

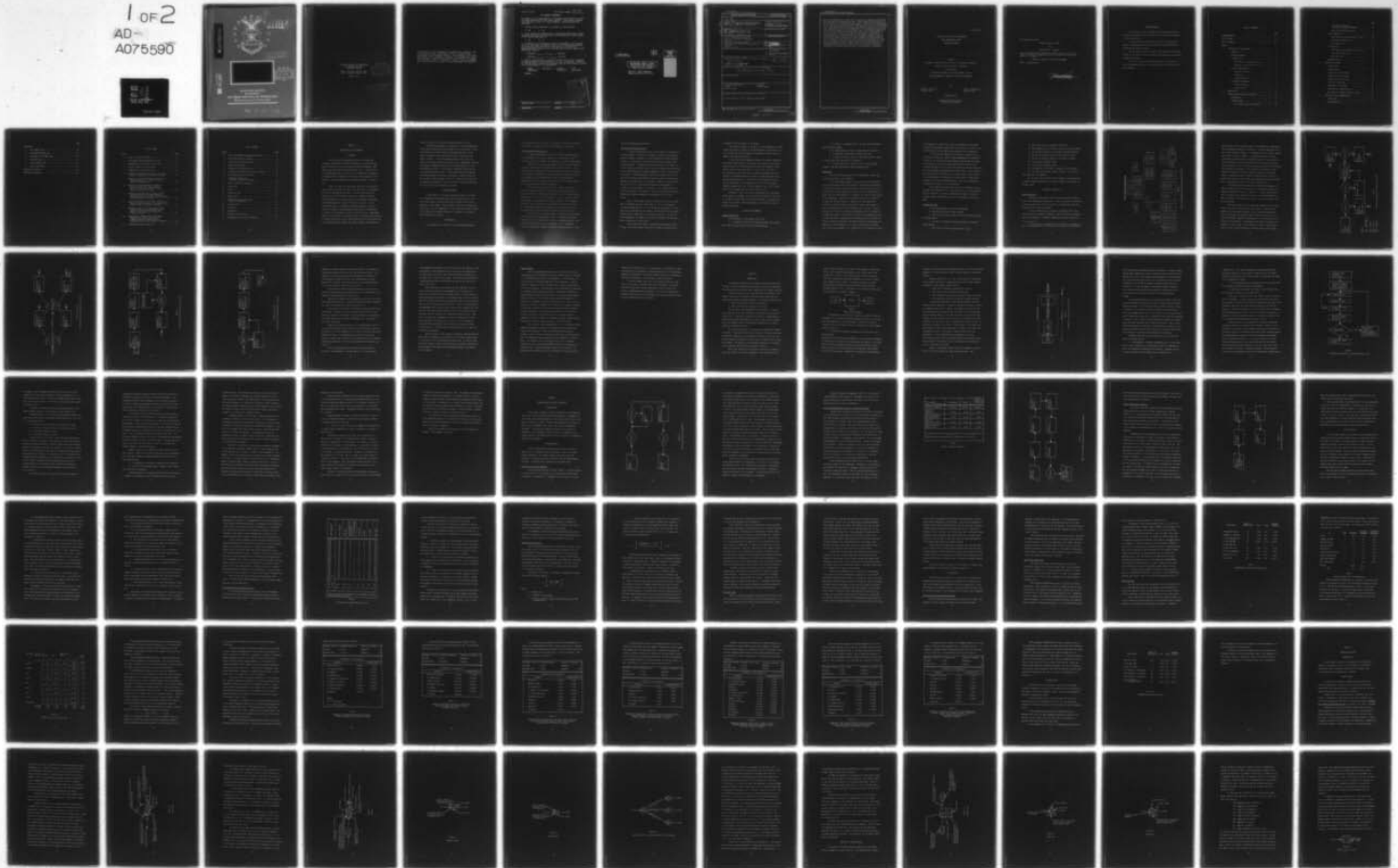
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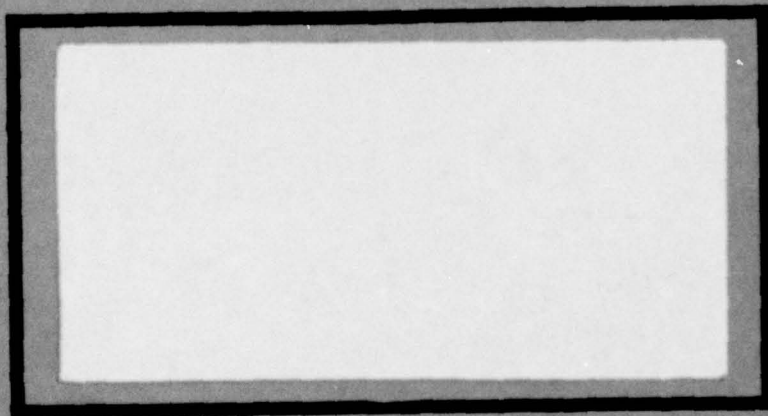
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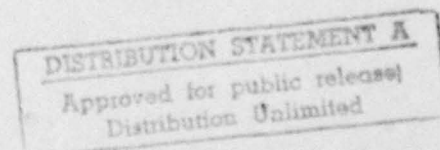
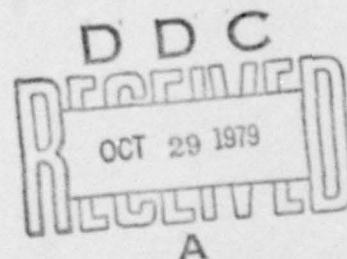
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A MODEL OF THE BASE CIVIL ENGINEERING
WORK REQUEST/WORK ORDER
PROCESSING SYSTEM

Walter A. Arnold, Captain, USAF
Dean G. Fogleman, Captain, USAF

LSSR 19-79B



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Base Civil Engineering is tasked with constructing, repairing, maintaining, and operating real property facilities. Within these areas falls most of the work which is accomplished by work order. Presently, Civil Engineering has no model for estimating work order completion time or for testing changes to the work order processing system. This research identifies the variables that significantly affect the accomplishment time and proposes a prototype model designed to predict this completion time. An extensive analysis was conducted to systematize the general structure of the work request/work order processing system and its behavior with respect to work order processing time. A conceptual model was developed to describe the work request/work order processing system as a stochastic queueing system in which the processing times and the various distributions are treated as random variables. Historical data was collected from Barksdale Air Force Base. An attempt was made to operationalize the conceptual model using the Q-GERT Network Analysis Program. The results of the model were inconclusive due to limits of the Q-GERT object program. However, the procedures to overcome these limitations are presented and discussed.

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A MODEL OF THE BASE CIVIL ENGINEERING

WORK REQUEST/WORK ORDER

PROCESSING SYSTEM

A Thesis

Presented to the Faculty of the School of Systems and Logistics
of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the
Degree of Master of Science in Facilities Management

By

Walter A. Arnold, BA
Captain, USAF

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September 1979

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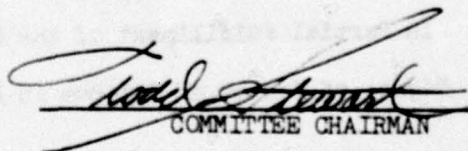
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Captain Dean G. Fogleman

has been accepted by the undersigned on behalf of the faculty of the
School of Systems and Logistics in partial fulfillment of the require-
ments for the degree of

MASTER OF SCIENCE IN FACILITIES MANAGEMENT

DATE: 7 September 1979


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TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	iii
LIST OF TABLES	vii
LIST OF FIGURES.	viii
 Chapter	
1. INTRODUCTION TO THE RESEARCH	1
OVERVIEW	1
PROBLEM STATEMENT.	2
JUSTIFICATION.	2
The Model as an Estimation Tool.	3
The Model as an Evaluation Tool.	4
SCOPE OF THE RESEARCH.	5
Research Objectives.	5
Limitations.	6
Research Questions	7
BACKGROUND INFORMATION	8
Current Situation.	8
Recent Studies	17
2. METHODOLOGY.	19
3. SYSTEM ANALYSIS AND DATA COLLECTION.	31
INTRODUCTION	31
SYSTEM ANALYSIS.	31
Work Request Approval Subsystem.	31

	Page
Work Order Planning and Material Acquisition Subsystem	34
Work Accomplishment Subsystem.	37
DATA COLLECTION.	39
Work Requests Received/Disposition Data. . . .	42
Work Request Sample Data	45
Work Order Data.	47
DATA ANALYSIS.	49
Work Requests Received/Disposition Data. . . .	49
Work Request Sample Data	50
Work Order Data.	51
ESTIMATES MADE	64
4. MODELING THE SYSTEM.	67
INTRODUCTION	67
Q-GERT SYMBOLS	67
ANALYSIS OF Q-GERT NETWORK	76
CONSTRUCTION OF THE MODEL.	82
OPERATIONALIZING THE MODEL	90
VALIDITY OF THE MODEL.	92
SENSITIVITY OF THE MODEL	93
THE MODEL AS A PREDICTION TOOL	95
THE MODEL AS A CHANGE EVALUATION DEVICE.	95
5. CONCLUSIONS AND RECOMMENDATIONS.	97
CONCLUSIONS.	97
RECOMMENDATIONS.	98

	Page
APPENDICES	
A. WORK REQUEST FORMS	99
B. WORK REQUEST SAMPLE DATA	102
C. CALENDAR OF WORK ORDER DATES	106
D. WORK ORDER DATA.	111
E. Q-GERT NETWORK MODEL	127
F. CODED Q-GERT MODEL	137
SELECTED BIBLIOGRAPHY.	151
BIOGRAPHICAL SKETCHES.	155

LIST OF TABLES

Table	Page
1. Levels of Approval Authority	35
2. Work Requests Received/Disposition Data.	43
3. CONDESCRIPTIVE--Work Request Sample Data	52
4. Special Interest Code Frequencies.	53
5. CROSSTABS--SI Code by Work Class	54
6. Regression--Estimated Man-hours on Work Class, Special Interest Code, and Number of Shops	57
7. Regression--Estimated Materials on Work Class, Special Interest Code, Number of Shops, and Estimated Man-hours.	58
8. Regression--Planning Man-days on Number of Shops, Estimated Man-hours, Estimated Materials, Work Class, Special Interest Code, and Priority 1 through 4	59
9. Regression--Planning Time on Number of Shops, Estimated Man-hours, Estimated Materials, Planning Man-days, Work Class, Special Interest Code, and Priority 1 through 4	60
10. Regression--Material Control Time on Number of Shops, Estimated Materials, Work Class, Special Interest Code, and Priority 1 through 4.	61
11. Regression--Time to Start on Number of Shops, Estimated Man-hours, Estimated Materials, Special Interest Code, Work Class, and Priority 1 through 4	62
12. Regression--In Progress Days on Work Class (Maintenance), Special Interest Code (Command Interest), Number of Shops, Estimated Man-hours, and Priority 1 through 4.	63
13. CONDESCRIPTIVE--Work Order Data.	65

LIST OF FIGURES

Figure		Page
1.	Base Civil Engineering Organization Chart.	9
2.	Written Work Request Flowchart	11
3.	In-Service Work Order Flowchart.	13
4.	Simple System Diagram.	20
5.	Schematic of Queueing Process.	22
6.	A Generalized Simulation Procedure Flowchart	25
7.	Work Request Approval Subsystem.	32
8.	Work Order Planning and Material Acquisition Subsystem	36
9.	Work Accomplishment Subsystem.	38
10.	Source Node.	69
11.	Q-Node	71
12.	Statistics Node.	72
13.	Regular Node	73
14.	Regular Node with Conditional-- Take First Branching	74
15.	Allocate Node.	77
16.	Free Node.	78
17.	Alter Node	79
18.	Calling of User Function	81
19.	Histogram for Actual Time in System.	94

Chapter 1

INTRODUCTION TO THE RESEARCH

OVERVIEW

The Air Force Civil Engineering activity is tasked with acquiring, constructing, repairing, maintaining, and operating real property facilities, as well as providing related management, engineering and other support work and services (12:2). In short, the Civil Engineering mission is service. The organization is generally the largest service organization on base and usually spends 40 to 60 percent of the total operations and maintenance budget of the base (3:1).

Within the tasks of constructing, repairing, and maintaining real property facilities falls most of the work which is accomplished by the Civil Engineering work order. The work order is used for virtually all minor construction work and for complex or special interest maintenance or repair work, which is performed by the Base Civil Engineering (BCE) in-service work force (14:p.8-1). Minor construction refers to alteration, additions, changes, or new construction required to provide adequate facilities for accomplishing the mission, and is generally limited to \$75,000 in cost. Maintenance refers to the recurrent, day-to-day, periodic or scheduled work required to preserve facilities in such a state that they may be used effectively for accomplishing their mission; and repair refers to work required to

return a facility to its effective operating state (13:p.2-1).

These work requirements are identified to Civil Engineering by various methods which are herein referred to as work requests. These work requests go through a series of processes which may include review, estimation, and approval before some of them become work orders (14:Ch.4). Once a work request becomes a work order, the series of processes continues with steps such as programming, planning, authorization, materials acquisition, and scheduling prior to work accomplishment (14:Ch.8). This series of processes constitutes the work request/work order system. In processing these work requests/work orders through this system of processes, a number of decisions must be made at various stages (14:Ch.4,8). Decision rules are used in making these decisions. Some of the decision rules are statutory, but many are locally established and informal.

PROBLEM STATEMENT

A need exists for a systemic mathematical model of the Base Civil Engineering work request/work order processing system. Such a model could provide accurate probabilistic estimates of the time to completion of work orders. These estimates could help to improve the credibility of the BCE organization. Such a model could also be useful in the evaluation of possible changes to the system or to decision rules employed in the system.

JUSTIFICATION

As mentioned above, a model of the work request/work order

processing system could be useful in two ways: as an aid to estimation of the time to completion and to evaluate changes in the system.

The Model as an Estimation Tool

A systemic mathematical model could provide accurate probabilistic estimates of the time to completion of work orders. These estimates could help to improve the credibility of the BCE organization.

Credibility in meeting commitments is one of the most important criteria by which Base Civil Engineering is judged (3:38,59). The customers of Civil Engineering, like customers of any service activity, are interested in knowing when they might expect the services or work they requested. This knowledge often helps the customer and his organization to plan for the inconvenience of mission jeopardy caused by not having the work performed immediately.

Limited resources and legal controls require that jobs be reviewed, evaluated, approved, controlled, and scheduled and that required materials be determined and obtained. All of these processes require time, not only for accomplishment, but also a waiting time to be processed. The processing times vary according to the complexity and type of work involved and the availability of resources for the job. The waiting times vary according to the number of other jobs in the system and the number of people available to process the jobs.

A valid model of the system based on mathematical relationships of the factors in the system might be able to generate a probability distribution function which could be used to accurately predict a timeframe within which a job should be completed (10:5). Subsequent completion within that timeframe should improve the credibility of the

Base Civil Engineering organization.

The Model as an Evaluation Tool

A systemic mathematical model could be useful in evaluation of possible changes to the system, or changes to decision rules employed within the system. Changes to the work request/work order processing system, or to the decision rules employed within that system, arise for many reasons. Governing directives and policies on the amount of control required on specific types of work, the organizational structure of Civil Engineering, and financial management all have some effect on this system. Locally established controls and decisions such as frequency of Facilities Board meetings, where some types of work must be approved, have their effect on the system. Changes to decision rules, such as the level of complexity which warrants accomplishment by contract, have their effect on the system. Also, changes which could improve the system or the quantity or quality of support the BCE could provide are frequently suggested by the people who work in the system.

Some of these changes undergo an extensive test at one or more bases to determine what the effects will be. This is an expensive and time-consuming process. If the test proves unsuccessful, the test base has been disrupted by the change to accommodate the test and again disrupted by the change back to the previous situation. If the test proves successful, the length of the test is time that could have been used to implement on a wider scale.

Other changes which affect the system are implemented without testing. With these changes, high levels of risk are incurred due to

uncertainty of the net effect of the change.

Some possibly productive changes are never implemented or tested because the risk is too great or the understanding of the system is too low to provide the intuitive reasoning necessary to indicate that the changes could improve the system.

A valid and flexible simulation model of the system, based upon mathematical relationships of the factors in the system, could enable proposed changes to be evaluated without risk, with relatively little expense, and in a very short period of time (2:477; 11:449-450). Such evaluation could provide data on average processing times, distribution of processing times, and number of workers required at the various processing points. This data could be compared to the data from the model prior to the changes; and the value of the changed average processing time, etc. could be compared to the value of other effects of the change, such as control gained or lost.

Therefore, a model of the work request/work order processing system needs to be designed to provide accurate estimates of the time to completion of work orders and to provide a means for evaluation of changes in the system. These requirements can be stated as specific research objectives.

SCOPE OF THE RESEARCH

Research Objectives

The objectives of this research effort were:

1. To describe the Base Civil Engineering (BCE) work request/work order processing system using the systems approach.

2. To develop a conceptual model of the BCE work request/work order processing system.
3. To operationalize the model through computer simulation.
4. To internally and externally validate the model.
5. To assess the model's ability to accurately predict a range of time in which work orders will be completed.
6. To assess the model's utility as a tool for evaluating changes to the work request/work order processing system.

Limitations

Due to the limited resources of the researchers, certain limitations were placed on this research:

1. The system was defined to be the in-service work request/work order processing system from receipt of request through completion of work by the shops or other dispositions; such as the decision that the work should be accomplished by contract or by Civil Engineering job order, that the work requested is not approved, or that the work request is not acceptable. Requests are considered received upon receipt of AF Form 332, BCE Work Request, or decision that work requested on AF Form 1135, BCE Real Property Maintenance Request (See Appendix A) might be appropriate work for accomplishment by work order. Requests for approval of work for self-help accomplishment were not modeled as entering this system. This limitation prevents any generalization that the model represents the entire work processing system as it exists in reality, because the portions of the system which are being modeled are impacted to varying degrees by job orders, contract work, self-help work, recurring maintenance, etc. Imposition of this limitation allowed

the researchers to model this portion of the system in much greater detail and with greater accuracy than could be done in a model of the entire system, with the limited time available to the researchers.

2. Only one BCE organization was used as a source of data. Using only one base as a source of data standardized the availability of data for all work requests/work orders flowing through the system. This limitation prevents any generalization that the model is universally applicable, and no contention is made that the base from which data was collected is representative of other bases. Only a portion of the data required for construction of a model, such as this, is kept as an official part of the records of the work order. Other data is available in the form of unofficial logs in some of the various processing points throughout Civil Engineering.

Even though this research was limited, the techniques could be extended both horizontally to include other methods of work accomplishment and vertically to include a representative sample of bases to construct models better suited to one of the possible uses of such a model.

Research Questions

The following research questions were addressed:

1. What are the sources of work requests?
2. What activities are included in the work request/work order processing system?
3. How are the different processes and variables within the system related?
4. What type of modeling technique should be used?

5. What type of input is needed for the model?
6. What assumptions must be made in order to model the system?
7. Can a simulation model of the system be operationalized?
8. How can the internal validity of the model be tested?
9. How can the external validity of the model be tested?
10. Is the model internally valid?
11. Is the model externally valid?
12. How sensitive is the model to changes in the variables?
13. How well does the model predict a range of time in which work orders will be completed?
14. How well does the model predict changes in processing time or number of people required, as a result of changes to the system or decision rules?

BACKGROUND INFORMATION

Current Situation

The BCE work request/work order processing system is operated by the Civil Engineering Organization. Before this system is described, it may be beneficial to briefly describe the organizational structure within which the system is operated.

At major installations, the Base Civil Engineer (BCE¹) works directly for the Installation Commander. Beneath the BCE are typically six or seven branches: Industrial Engineering; Squadron Section and

¹BCE is the common abbreviation for both Base Civil Engineer and Base Civil Engineering. The meaning should be clear from the context.

Base Civil Engineer Organization Chart

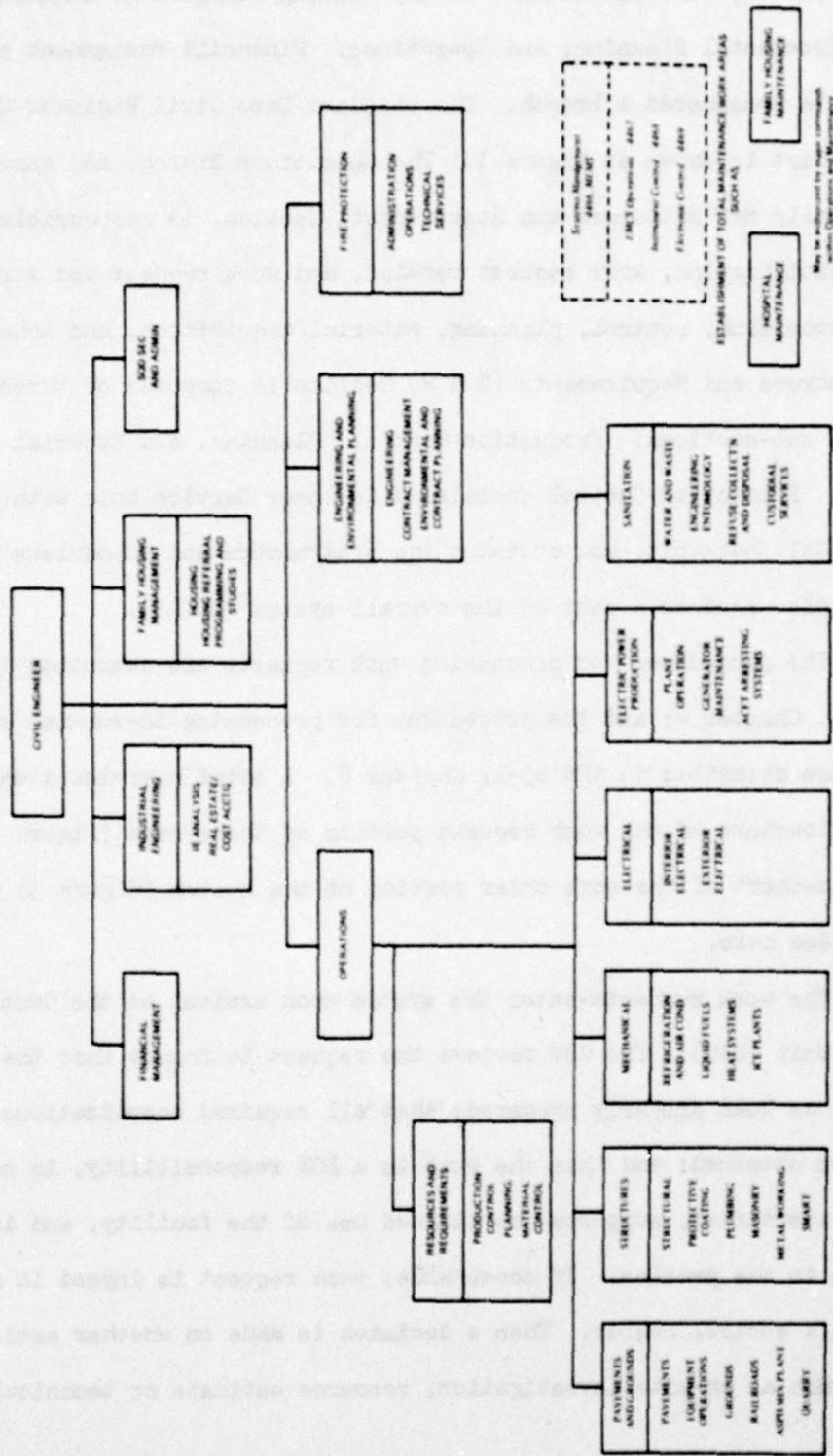


Figure 1
Base Civil Engineering Organization Chart [12:19]

Administration; Fire Protection; Family Housing Management; Engineering and Environmental Planning; and Operations. Financial Management may or may not be considered a branch. The standard Base Civil Engineer Organization Chart is shown at Figure 1. The Operations Branch, and more specifically the Resources and Requirements Section, is responsible for work identification, work request receipt, and work request and work order processing, control, planning, material acquisition, and scheduling. The Resources and Requirements (R & R) Section is composed of three separate sub-sections: Production Control, Planning, and Material Control. Production Control contains a Customer Service Unit with a Service Call sub-unit, and contains the programmers and schedulers which will be discussed as a part of the overall system (12:15).

The procedures for processing work requests are described in AFR 85-1, Chapter 4; and the procedures for processing in-service work orders are described in AFR 85-1, Chapter 8. A brief overview along with a flowchart of the work request portion of the system (Figure 2) and a flowchart of the work order portion of the system (Figure 3) will be provided here.

The work requests enter the system upon arrival at the Customer Service Unit (CSU). The CSU reviews the request to insure that the request has been properly prepared; that all required coordinations have been obtained; and that the work is a BCE responsibility, is not already identified, supports the planned use of the facility, and is a solution to the problem. If acceptable, each request is logged in and assigned a control number. Then a decision is made on whether assistance, such as on-site investigation, resource estimate or technical

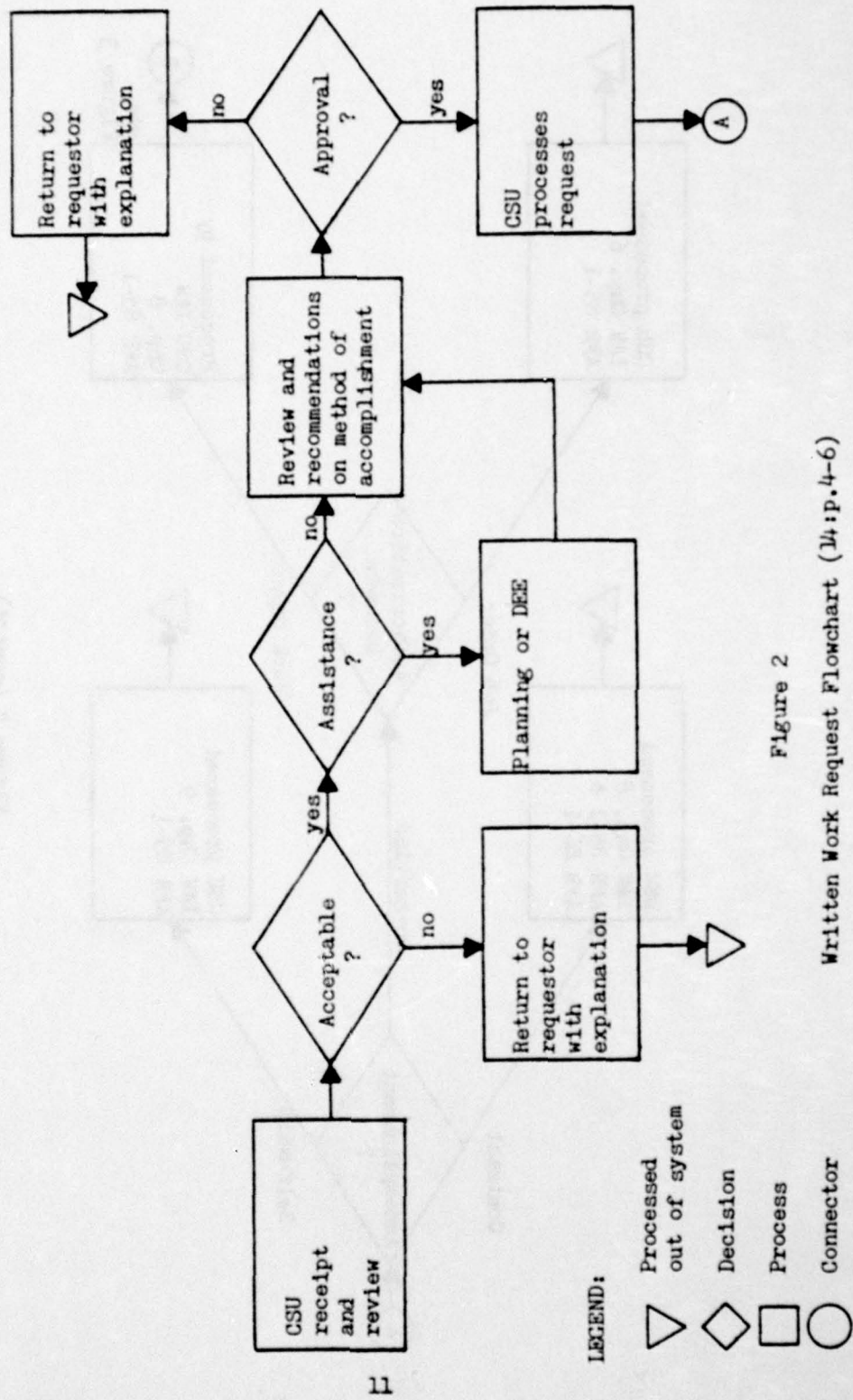


Figure 2

Written Work Request Flowchart (U:P.4-6)

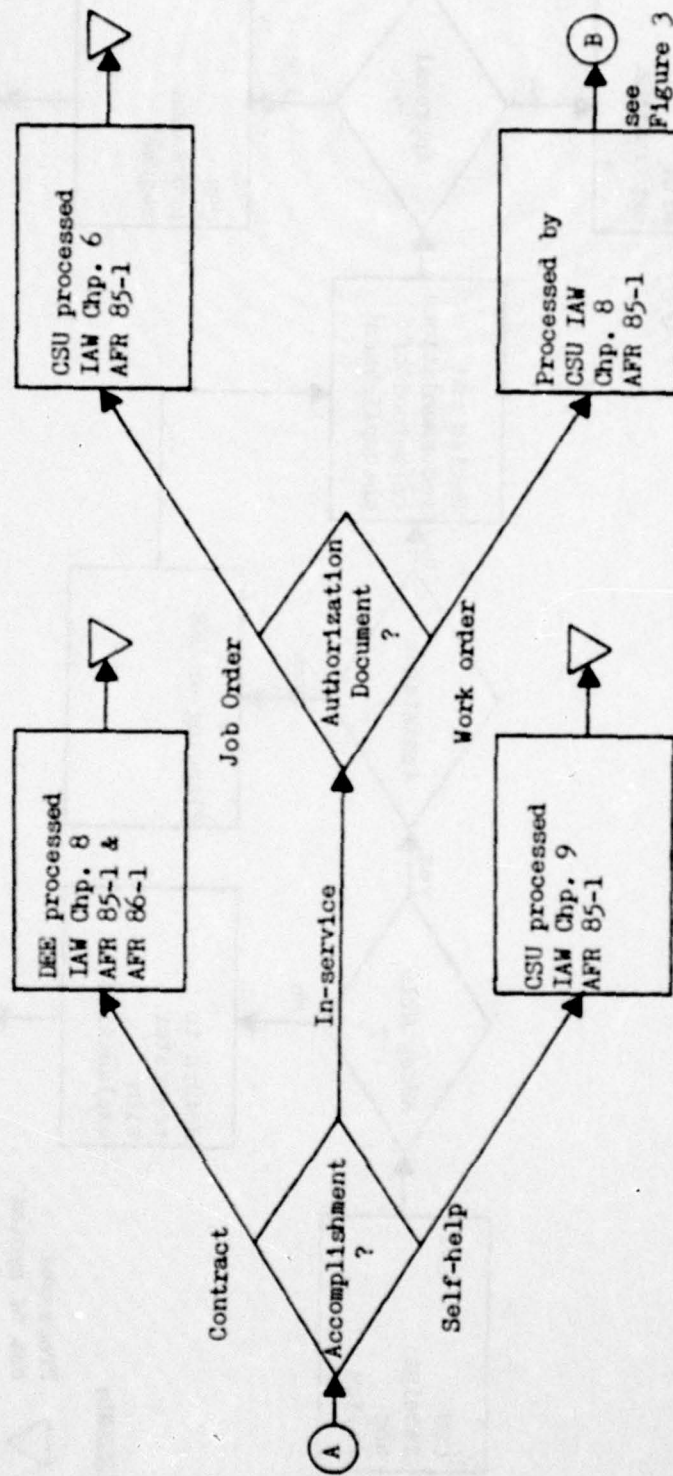


Figure 2 (cont'd)

Written Work Request Flowchart (14ip.4-6)

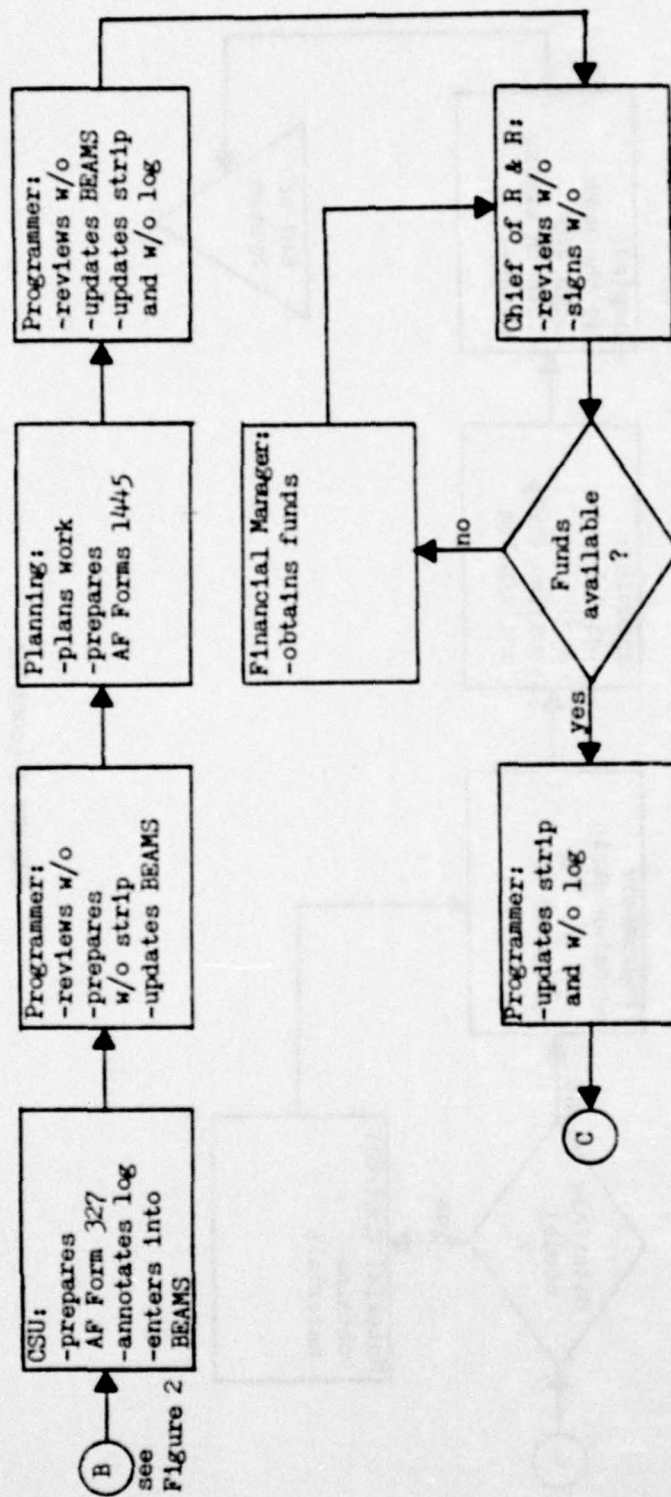


Figure 3

In-Service Work Order Flowchart (14:p.8-6)

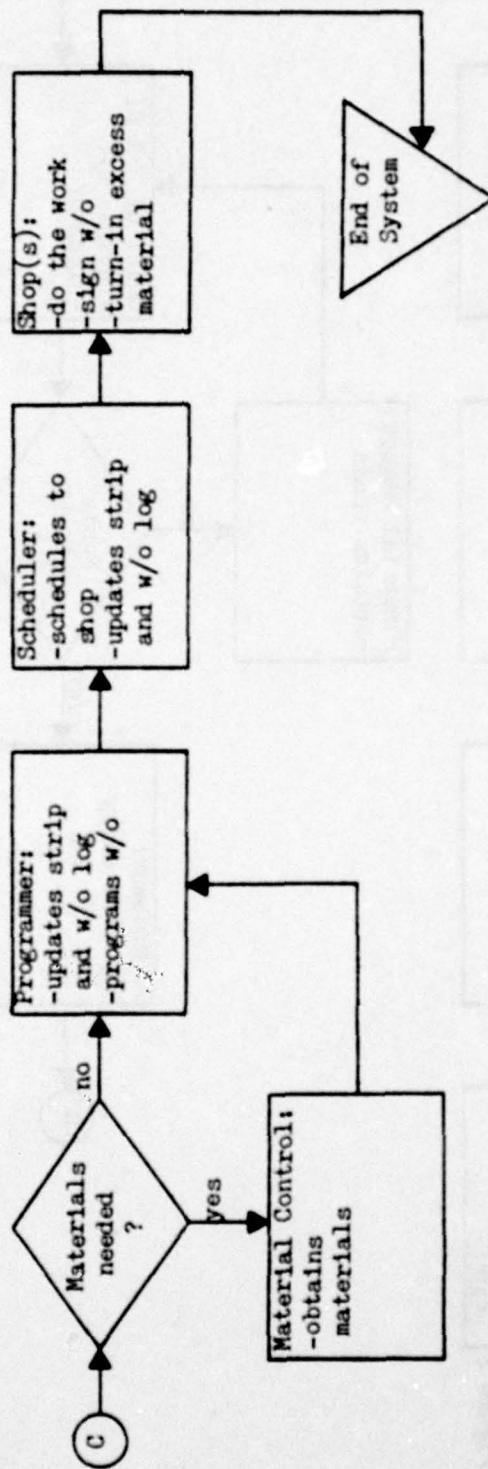


Figure 3 (cont'd)
In-Service Work Order Flowchart (14:p.8-6)

evaluation, is needed prior to an approval decision. If assistance is needed, each request is routed to the office which can assist. Upon completion of the assistance process, recommendations on method of accomplishment are made by the CSU, and a determination of proper approval level is made. Each request is then routed through channels to the proper approval authority (14:pp.4-1,4-2).

Requests which were initially unacceptable or which are disapproved by proper authority are processed out of the system back to the requestor with an explanation (14:pp.4-2,4-3).

Approved work requests are processed by the CSU into one of four work accomplishment methods: contract, self-help work order, in-service job order, or in-service work order (14:pp.4-2,4-3).

This study has been limited to the work request/in-service work order system. Therefore, work to be accomplished by contract or in-service job order will be assumed to leave the system once processed by CSU, while requests for self-help accomplishment will be assumed to never enter the system.

Approved work requests which are to be accomplished by the in-service work order method are processed into the work order portion of the system by the CSU's preparation of the draft AF Form 327, Base Civil Engineer Work Order. The programmer then reviews the work order, records its status, and forwards it to the Planning Section for detailed planning and preparation of AF Form 1445, Materials and Equipment List (14:p.8-2).

When the planning process is complete, each work order is returned to the programmer for records updating. The work order is

then forwarded to the Chief of R & R for review and authorization. This authorization is the certification that the job has been approved and that resources in the form of shop labor and money for materials may be legally used on that job as planned. If funds are not available for a particular work order, the work order must wait until funds can be obtained (14:p.8-2).

When authorization and funding have been completed, the work order records are updated by the programmer; and if materials are needed, the work order is sent to Material Control to obtain materials. When materials are all available, the programmer again receives the work order, then updates the record and programs the work into the In-Service Work Plan for a particular month (14:p.8-2). Prior to the beginning of the programmed month, the work order is given to the scheduler who, with the help of the shop foreman, schedules the job for a particular week and day(s) that the work will be accomplished (14:pp.8-2,14-2). When the job is scheduled, consideration is given to availability of manpower, equipment and vehicles, and job site, as well as proper job sequencing among the different shops working on the same work order (14:pp.14-2,14-3). The work order is then turned over to the shop and the work is accomplished.

Since the impact on the customer is generally completed when the work itself is completed, this completion will be operationally defined to be the end of our work request/work order system. In reality, each work order undergoes several other processes in paperwork completion and records keeping before the Civil Engineering personnel could consider the job complete.

Recent Studies

The Civil Engineering Systems Division of the Air Force Data Systems Design Center (AFDSDC) has conducted several studies in the area of Civil Engineering maintenance and management. Of the studies conducted thus far, none have attempted any form of modeling. Only one study (4), completed in 1973, has dealt with the area of work request/work order processing. This particular study investigated the potential of utilizing data processing techniques to improve BCE procedures for maintaining the In-Service Work Plan (IWP). The study proposed making maximum utilization of new computer technology and elimination of duplication of management efforts where they existed. As part of this proposal, the report recommended that a man-machine interface procedure be developed to maintain continuously accurate IWP, weekly schedules, and daily schedules. The current process offers no effective way to evaluate the validity of the monthly plan nor is there sufficient management information feedback to adequately forecast changing resource requirements or effects these changes have on the IWP process.

A 1978 Air War College Research Report (3) by Lieutenant Colonel Burgess investigated the degree of consistency among individuals who evaluate the performance of Base Civil Engineering organizations. Through the use of a survey questionnaire, responses were received from Base Civil Engineers, Base Commanders, and Wing Commanders at various bases. The objective of the questionnaire was to elicit judgment concerning the most important performance evaluation criteria and the techniques used to measure performance against those criteria. The research report concluded that the two performance evaluation criteria

selected most important by all (as a group) were (1) credibility to meet commitment and (2) satisfaction of base personnel with Civil Engineering organization performance. The report further concluded that performance measurement techniques in use were almost entirely subjective.

The above studies, while they do not relate directly with the topic of this thesis, do provide some useful information. The AFDSDC study dealt mainly with computer applications, but did mention the problem of changing resource requirements. The Air War College report supported the proposition that credibility and customer satisfaction are considered important evaluation criteria.

Chapter 2

METHODOLOGY

This chapter describes how the research effort was carried out. The plan of attack for addressing the research objectives is discussed. Also discussed are the methods used in addressing the research questions.

Research questions 1 and 2 were developed for meeting the first research objective--to describe the BCE work request/work order processing system using the systems approach. The research questions were:

1. What are the sources of work requirements?
2. What activities are included in the system?

The sources of work requirements were identified in Chapter 1 as AF Forms 332 and AF Forms 1135 which are received by the Production Control Unit. In addition, requests are received by correspondence or directive from higher headquarters, by word of mouth, and by telephone. Thus, this research question was answered by examination of current directives, especially AFR 85-1.

The activities included in the system were described in general in Chapter 1. The specific activities included in the system model were established by augmenting the procedures as described in AFR 85-1 with actual procedures at Barksdale Air Force Base, Louisiana, where the data were obtained. See Chapter 3 for a detailed description of procedures found at Barksdale which were not described in Chapter 1.

Each of the processes in the system, along with its immediate inputs and outputs, constitutes a subsystem. The activities for the

overall system are looked at in terms of the subsystem to which they belong. Each subsystem was analyzed in terms of what inputs were required and in terms of what output resulted from the processing. After all subsystems were described according to the Input--Process--Output fashion shown in Figure 4, they were combined to provide a systems approach description of the BCE work request/work order processing system (11:17). Development of the conceptual model using such an approach is included in Chapter 3.

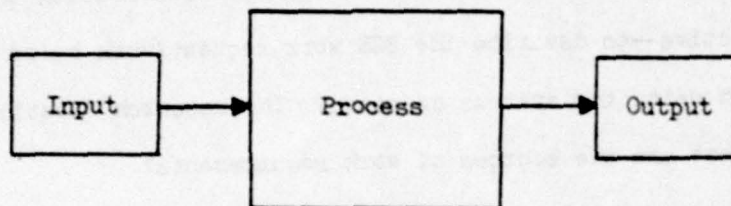


Figure 4

Simple System Diagram

The answers to these first two research questions provided the description of the process, and enabled research objective 1 to be met. With this description, the second research objective--to develop a conceptual model of the system--was met by answering the third research question, which was:

3. How are the different processes and variables within the system related?

Answering this question involved examination of the process at Barksdale Air Force Base to determine how the subsystems were related. This determination involved placing the simplified process subsystems in their proper sequence, and then determining any mathematical relationships involved in the processes. Determining the mathematical relationships

involved in the processes was accomplished through use of the Statistical Package for the Social Sciences (SPSS) computer program as described in Chapter 3.

Research questions 4, 5, 6, and 7 were proposed for meeting the third research objective--to operationalize the model through computer simulation. These research questions were:

4. What type of modeling technique should be used?
5. What type of input is needed for the model?
6. What assumptions must be made in order to model the system?
7. Can a simulation model of the system be operationalized?

As previously mentioned, the BCE work request/work order processing system is basically a queueing or waiting line system. Figure 5 is a general model of such a system. Work requests are received from the calling source (customer) and are input into the work request/work order processing system. If the service facility can be entered immediately, the unit is served and then moves on to another activity node; otherwise, the unit joins a queue or waiting line to await service. As explained in Chapter 1, the output, or final result of the request and all processes, is the work accomplishment. In Figure 5 the term queue configuration refers to the number of available queues and their arrangement. In Civil Engineering this represents the various activities which make up the work request/work order processing system. Queue and service disciplines refer to the behavior and processing of units in the system (2:431-432).

Q-GERT, a specialized computer simulation language, was used to model the BCE work request/work order processing system. This

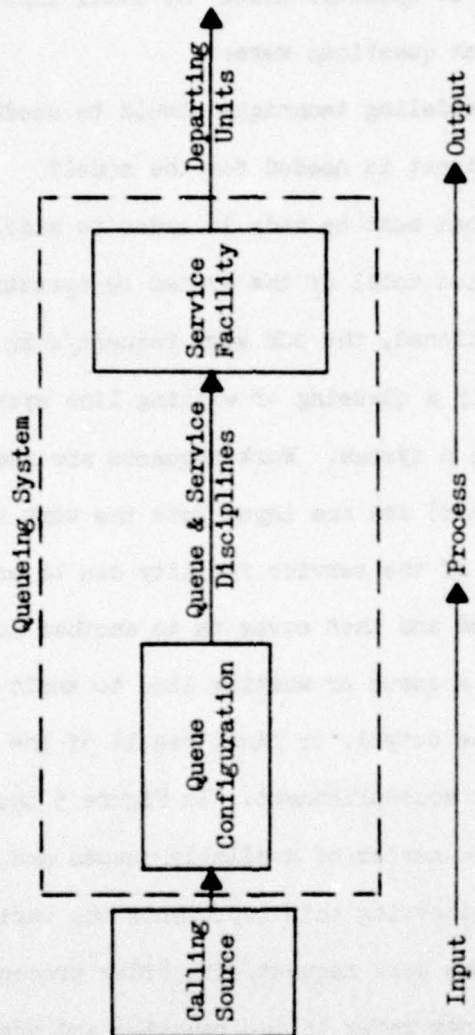


Figure 5
Schematic of Queuing Process (2:432)

particular simulation program provides the capability to analyze complex systems where queueing can occur at various processing points within the system (6:215; 8:3). This technique is applicable to the work request/work order processing system since any job requirement prior to accomplishment must go through the various activities within the system (10:134-135). As each requirement is processed through the system, it goes through several waiting lines; therefore, an appropriate way to model this type of activity was by use of the Q-GERT simulation package.

The question relating to type of input data needed to model the system was answered by attempting to model the system using the Q-GERT simulation package. It was found that data concerning the rate of input of requests to the system, the number of servers at each processing point, the average service time for each process, and the decision rules used in selecting the next job to be served at each process were required. In addition, data to support either probabilistic branching or decision rules upon which branching could be made were required. Data of these types were requested of personnel who work within and in support of the system at Barksdale Air Force Base, Louisiana. Data were obtained from both official and unofficial records maintained at Barksdale.

Barksdale Air Force Base was selected for use as a data base source for several reasons:

1. BCE underwent a worldwide reorganization on 1 October 1978. Prior to this reorganization, several bases tested the reorganization plan, thus undergoing reorganization much earlier. Barksdale was one of these test bases, having undergone this reorganization on

1 February 1977. As a result, Barksdale's work request/work order processing system had over two years of operation under the current worldwide system without the bias which might be associated with making such a reorganization change.

2. The researchers had some familiarity with the base and with the personnel who operate the system at Barksdale.

3. Personnel at Barksdale had offered to make available any data necessary to support this research effort.

Some items of input data which were needed to model the system were not available. In these instances, either estimates were made by the personnel who worked with the system or assumptions were made by the researchers based upon their knowledge and experience with similar systems. A complete discussion of the data collected and the estimates and assumptions made, as well as the use of the data for developing inputs into the system simulation model, is included in Chapters 3 and 4. This discussion answers research questions 5 and 6.

Research question 7 was addressed by following a generalized simulation procedure as depicted by the flowchart in Figure 6. This flowchart is a summation of the systematic approach which was taken in developing a model of the BCE work request/work order processing system. The system parameters, decision rules, and performance requirements found by answering questions 3, 4, and 6 were input into the model. Simulated processing was to have been accomplished by the computer. After simulating the model a number (n) of times, output was to have been produced in the form of operating statistics. These operating statistics can be generated for each of the performance characteristics

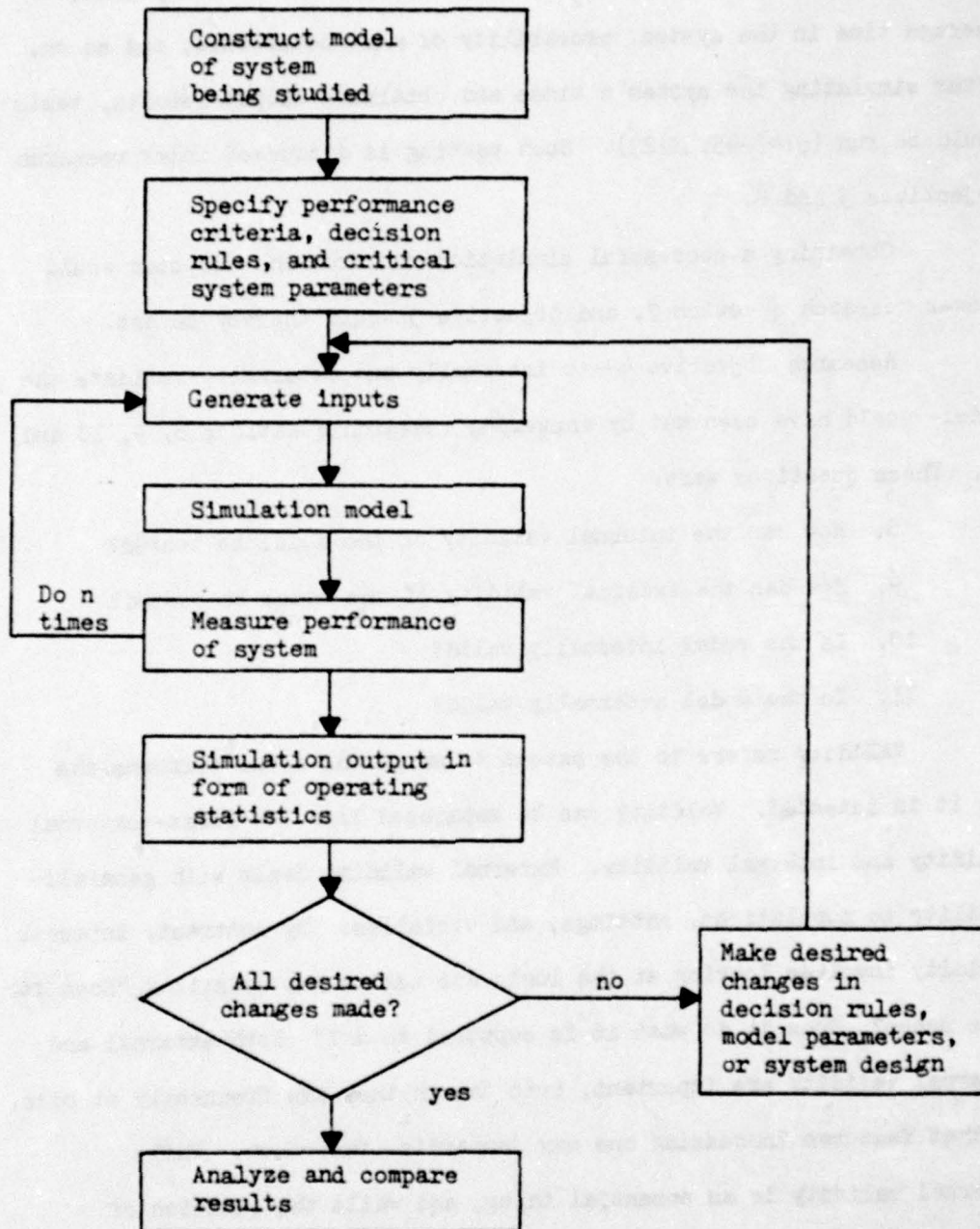


Figure 6

A Generalized Simulation Procedure Flowchart (6:44)

of interest, such as average processing time at each activity node, average time in the system, probability of event occurrence, and so on. After simulating the system n times and obtaining output results, tests would be run (6:43-45; 10:23). Such testing is discussed under research objectives 5 and 6.

Obtaining a successful simulation run from the computer would answer research question 7, and objective 3 would thereby be met.

Research objective 4--to internally and externally validate the model--would have been met by answering research questions 8, 9, 10 and 11. These questions were:

8. How can the internal validity of the model be tested?
9. How can the external validity of the model be tested?
10. Is the model internally valid?
11. Is the model externally valid?

Validity refers to the extent to which the model performs the way it is intended. Validity can be separated into two forms--external validity and internal validity. External validity deals with generalizability to populations, settings, and variables. By contrast, internal validity involves looking at the logic and asking the questions, "Does it make sense? Does it do what it is supposed to do?" Both external and internal validity are important, even though they are frequently at odds, in that features increasing one may jeopardize the other. While internal validity is an essential thing, and while the question of external validity is never completely answerable, both are strived for (5:120,303).

The internal validity of the model would have been tested by

comparing the statistical results obtained from the simulation with descriptive statistics of the data collected from Barksdale. This comparison would have been accomplished using Chi-Square goodness of fit tests to compare the simulated work request dispositions with the dispositions of the sampled data, and to compare the length of time each completed work order spent in the system.

The external validity of the model could have been tested by comparing the results of the simulation to a population broader than that used in construction of the model to insure that the results are generalizable. Since this model was limited to data collected from one Air Force Base, generalization beyond that Base and timeframe was not attempted; and since all available data was used in construction of the model, no test of external validity can be made at this time. The question of external validity would have to be answered when any attempt were made to apply this model to a broader scope. Conducting the Chi-Square tests would have lent internal validity to the model, and research objective 4 would have been met.

Research objective 5--to assess the model's ability to accurately predict a range of time in which work orders will be completed--was to have been attained by answering research questions 12 and 13.

These questions were:

12. How sensitive is the model to changes in the variables?
13. How well does the model predict a range of time in which work orders will be completed?

Answering question 12, concerning the sensitivity of the model to changes in the variables, would be necessary prior to use as a

-

prediction model. This provides the user with a feel for what will happen to the result if changes occur in future parameters or data which were used to construct the model (11:182). The testing would be conducted by taking a "no" decision in the decision block of Figure 6, then making changes in decision rules or model parameters one at a time. The simulation would then be conducted with the change, and results compared to the model with no changes included.

Answering question 13 would involve combining information concerning the validity of the model from question 9 with information concerning the sensitivity of the model from question 12 and with some knowledge of the system and prediction information requirements. Since this is a stochastic and dynamic system, an exact completion date prediction is a virtual impossibility. The model should produce a probability function of completion dates from which a completion time range can be selected depending upon the degree of accuracy desired to be captured within that range.

There are no guidelines on how accurate an estimate is required or how narrow the confidence interval must be. Common sense dictates that the estimate must be usable, in light of given information. For example, if the only information about a request is the time of arrival at the CSU, a 95 percent confidence interval prediction of "between two weeks and fourteen months" might be reasonable and useful. But if it were known that a request would become a minor construction work order, was within the BCE's approval authority, had funds available, and required no materials which were not on hand, then a 95 percent confidence interval prediction of "between one month and twelve months" would

probably not be very useful.

Since there are no guidelines on how accurate predictions need to be and because there is no real prediction method available now, nor records of predictions which are made, the final answer to question 13 was to have been subjectively based upon the question, "Is the information reasonable and usable?" Answering questions 12 and 13 would have met objective 5.

Meeting research objective 6--to assess the model's utility as a tool for evaluating changes to the system--would require an answer to research question 14, which was:

14. How well does the model predict changes in processing time or number of people required, as a result of changes to the system or decision rules?

Answering this question would again involve taking the "no" decision block of Figure 6, then making desired changes in decision rules, model parameters, or system design. For example, if one were interested in the change in the probability of a successful outcome due to new procedures, he would change one of the decision rules or logic of the system. As another possibility, one might be concerned about the sensitivity of the total time to a change in the time duration of a particular activity. This concern could be addressed by varying the activity time parameter. When the desired changes were made to the model, simulation would again be conducted, and the results on the total process observed (6:43-45; 10:23).

Analysis of the results would have been primarily subjective, since there is no standard of how good a test should be. The "reasonable

and usable" criterion would again be used. The average total processing times would become more important in the results used for evaluation purposes, since the effect on each single work request/work order ceases to be a criterion. Therefore, it is possible that favorable results can be obtained in using the model as an evaluation tool, even if the model was of little or no value as an estimator. With the answer to research question 14, research objective 6 would have been met.

The model could not be successfully operationalized within the time constraints imposed, but a discussion of the reason for this and of changes to the Q-GERT program which will allow successful operationalization is included in Chapter 4.

With this discussion and a discussion of further research of Chapter 5, this research is complete.

Chapter 3

SYSTEM ANALYSIS AND DATA COLLECTION

INTRODUCTION

This chapter contains a detailed description of the procedures used in the work request/work order processing system at Barksdale Air Force Base, using a systems approach. With this systematic model of the system, collection of data to describe the parameters of the system as well as input, throughput, and output times of each subsystem are discussed. A discussion of parameter estimates is followed by a description of data analysis using the Statistical Package for the Social Sciences. The chapter concludes with a discussion of assumptions made by the researchers.

SYSTEM ANALYSIS

The work request/work order processing system, as shown in Figure 2 and 3 of Chapter 1, can be described in terms of its three primary subsystems: work request approval subsystem, work order planning and materials acquisition subsystem, and work accomplishment subsystem. These individual subsystems are discussed below.

Work Request Approval Subsystem

The work request approval subsystem (Figure 7) covers the period of time from entry of the request into the work request system until its approval or disapproval. At Barksdale Air Force Base, one of the

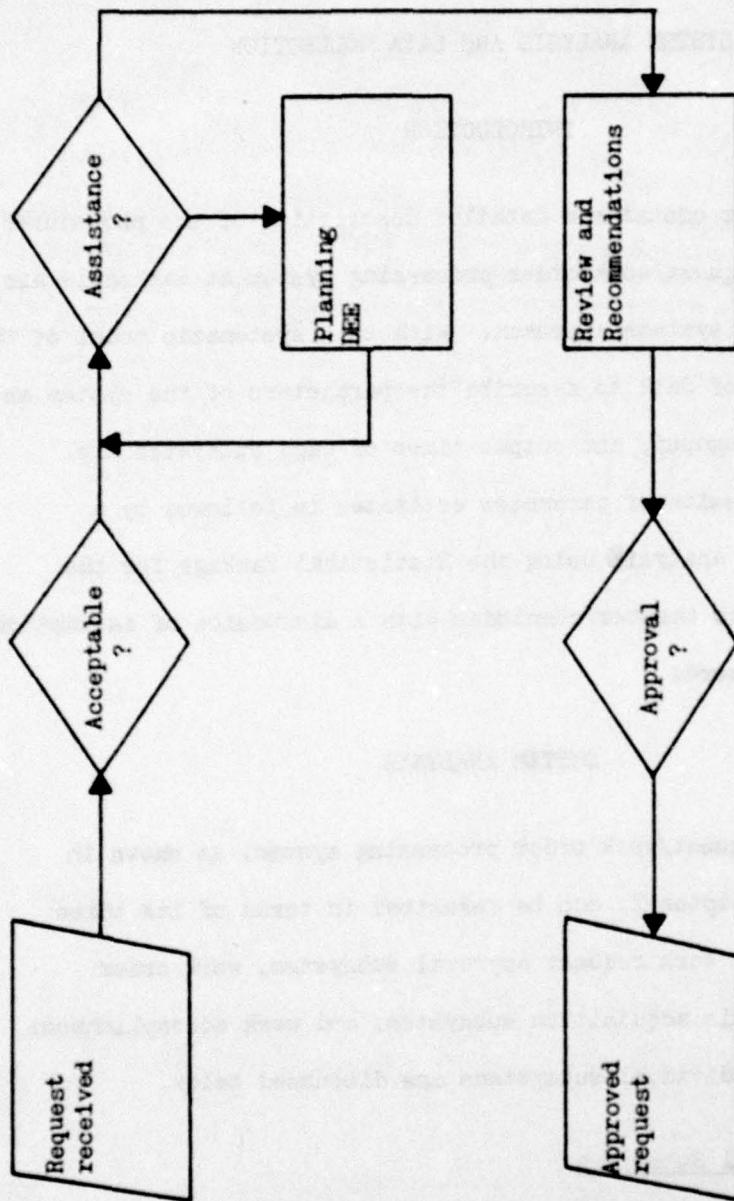


Figure 7
Work Request Approval Subsystem

philosophies of management was found to be that any work which can possibly be accomplished by job order is accomplished in that manner. This philosophy was evident in the operation of the Customer Service Unit, where requests are initially routed into either the job order processing system or the work request/work order processing system. In the CSU, all requests which initially appear to be accomplishable by job order are routed into that system rather than into the work request system. Subsequently, it is found that many of the requests are not accomplishable by job order. These requests then enter the work request system several days after having been initially received by the CSU. The CSU maintains a control document, the work request log, of all work requests/work orders in the system. The log entry for "date received" is actually the date the request entered the work request system. The beginning point of the system is, therefore, receipt of written or verbal work requests which are immediately entered into the work request system, and receipt of AF Forms 332, Base Civil Engineering Work Requests, which are determined to be unacceptable. Although not entered into the work request log, an unofficial log of AF Forms 332 which were determined to be unacceptable is maintained by the Customer Service Specialist at Barksdale.

The function of the work request subsystem is to process the request through approval or disapproval. The inputs to the subsystem are requests for work. The outputs from the system are unacceptable requests, approved requests, and disapproved requests. Disapproved requests are returned to the requestor. For those requests which are approved, a method of accomplishment is recommended.

Approval authority is delegated by AFR 86-1 to the Major Air Command Commander, with authority to redelegate all or part of the approval authority to lower levels. See Table 1 for the levels of approval authority in effect at Barksdale.

Work Order Planning and Materials Acquisition Subsystem

Approved work requests with in-service work order as the method of accomplishment are the input into the second primary subsystem, the Work Order Planning and Materials Acquisition Subsystem (Figure 8). After an update of records, a Base Civil Engineering Work Order (AF Form 327) is initiated. These work orders are processed by the Planning Section to provide the estimated man-hours and Materials and Equipment List (AF Forms 1445) if required. The work orders are routed through the Chief of Resources and Requirements for authorization if funds are available. At Barksdale, work orders are not routed through Funds Management to certify funds availability. Rather, Funds Management maintains a continuous information flow to the various approval authorities so that funds availability is one factor considered in work request approval or disapproval. In addition, the information flow to the Chief of R & R provides the opportunity to delay any approved work in light of recent funding developments.

After authorization by the Chief of R & R, the work orders records are updated by the Programmer. Afterwards, if any materials are required, the work order is forwarded to material control for materials ordering and receipt. When all required materials are on hand, the Programmer receives the work order for records updating. Completion of this records update represents the completion of the

FOR TO	Maintenance	Repair	Minor Construction (In-Service)
Base Civil Engineer	\$100,000	\$50,000	\$25,000
Chief of Operations	25,000	25,000	10,000
Chief of Resources and Requirements	25,000	25,000	5,000
Chief of Production Control	25,000	25,000	2,500
Chief of Customer Service Unit	25,000	25,000	2,500
Projects above the BCE's approval authority must be validated by the Facilities Board, then approved at MAJCOM level or above (1)			

Table 1
Levels of Approval Authority

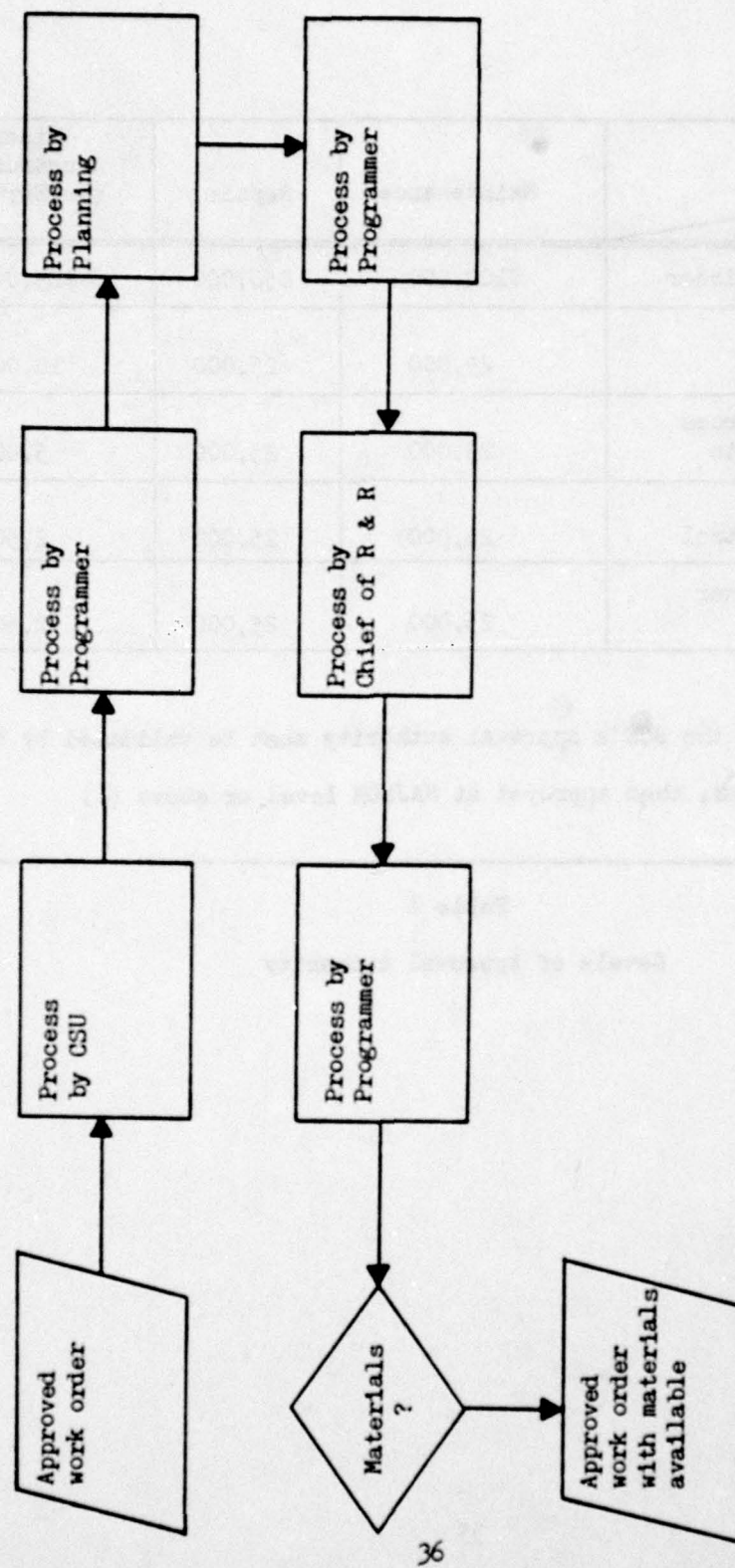


Figure 8

Work Order Planning and Materials Acquisition Subsystem

Work Order Planning and Materials Acquisition Subsystem. The output of this subsystem is work orders which have been planned, authorized, and all required materials received.

Work Accomplishment Subsystem

The outputs of the Work Order Planning and Materials Acquisition Subsystem are the inputs into the Work Accomplishment Subsystem (Figure 9). In this subsystem, the Programmer programs the work order into the First Future Month In-Service Work Plan (IWP) when adequate shop man-hours are projected to be available. Near the end of each month, all work orders on the IWP for the following month are forwarded to the scheduler for scheduling into one or more of the weekly and daily schedules.

At Barksdale, the IWP Programming function and the scheduling function are accomplished by the same individuals, called schedulers. On Monday of the week prior to scheduled work start, copies of the work order are sent to all shop foremen scheduled to work on the job. The shop foremen check the job and present any problem areas, such as non-availability of equipment, nonavailability of job site, or not enough or incorrect materials, to the schedulers at their shops pre-scheduling meeting on Wednesday. If the problems cannot be resolved by completion of a full scheduling meeting held on Thursday, the job is not scheduled for the following week. If materials must be reordered, the work order is returned to the Material Control portion of the previous subsystem. When the reordered materials are on hand, the work order generally is programmed into the current month IWP. If the problems were with non-availability of equipment or job site, the job is delayed and considered

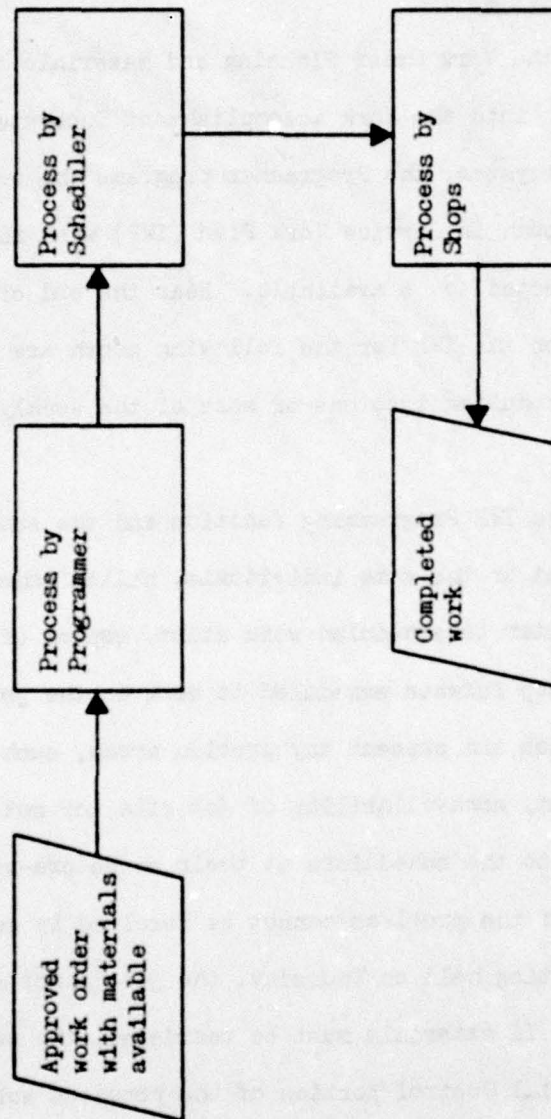


Figure 9
Work Accomplishment Subsystem

again the following week. When no unresolvable problems occur, the foremen begin work during the next week.

Work is accomplished on each work order by the shops programmed on that job. When all required work is completed for any shop, the foreman signs the work order and forwards it to scheduling. When scheduling has received a signed copy of the work order from each shop foreman, the work is complete. Work completion represents the end of this final subsystem of the Work Request/Work Order Processing System. Thus, completed work is the output of both the Work Accomplishment Subsystem and the Work Request/Work Order Processing System.

DATA COLLECTION

To run a Q-GERT simulation of the Base Civil Engineering work request/work order processing system requires some parameters for the activities of the system. The Q-GERT simulation program processes transactions through a network of activities and nodes. For this research effort, each work request/work order is represented by one transaction moving through a network of nodes representing processing points or milestones, along a series of activities, representing the processes. Branching is allowed to occur at nodes. Parameters are required for arrival rate at the first node in the network, for processing time at each activity within the network, and for making branching decisions from the nodes.

Each BCE office maintains certain files which contain data useful to development of some of the parameters required for modeling such a system. These files are:

1. Work Request/Work Order Log which contains dates that each work request was received and disposition of each work request, as well as dates that each work request was sent to and/or received from some of the processing points in the work request portion of the system. The Work Request/Work Order Log from Barksdale was the primary source of data concerning arrival rate of requests, routing of requests, and disposition of requests.

2. Completed Work Order Files which contain work order folders of completed work orders. Each work order folder contains a copy of the Completed Work Order Cost Report which shows Work Class, Special Interest Code, Priority, Work Order Indicator, Number of Shops, Estimated and Actual Man-hours, Estimated and Actual Materials, Date Opened, Material Order and Receipt Date, Date Start, Date Complete, as well as other data. These data elements will be explained later. In addition, each folder contains a copy of the work order showing the date authorized, and a copy of the work request showing the date approved and the signature of the approval authority.

3. Work Order History Tape which is a computerized record maintained on tape for a moving twelve-month period. This master file contains all information available on the Completed Work Order Cost Report and some other data which was not mentioned.

At Barksdale, a copy of the Work Order History Tape is on hand as of completion of end-of-month processing at the end of September 1978, containing work order master records of all work orders in the computer system during the period 1 October 1977 through 30 September 1978. This tape and the current Work Order History Tape were used

as the primary means of identification of work orders which had traversed the system since the reorganization test began 1 February 1977.

The following less formal and unofficial sources of data were found to be available at Barksdale:

1. The Customer Service Unit maintained a separate list of AF Forms 332, Base Civil Engineering Work Requests which were returned to the requestor as being unacceptable, without having been logged in.

2. The Planning Section maintained a log of work requests received for evaluation with work request number, date logged in, date logged out, and number of planning man-hours used.

3. The Planning Section maintained a log of work orders received for planning with work order number, date logged in, date logged out, and number of planning man-hours used.

4. Scheduling maintained a list of work order numbers by the date that the work order folder was sent to the Material Control Section.

5. The Material Control Section maintained a log of work order numbers with dates that the work order folders were received and sent back to scheduling, and where appropriate, dates that the work order folders were received and sent back second and third times.

6. Scheduling maintained a list of work order numbers by date that work was completed by the last shop to complete its work on that job.

Development of the system model required the collection of data from the operation of the system, such as frequency or rate of arrival of requests, processing time, and method of accomplishment. In several

cases the desired information was only available in the unofficial files maintained by the workers. The researchers felt that the information in these files was accurate and relevant. By searching out and tapping all of the relevant and available sources of information, the researchers get a more accurate picture of the situation; therefore, can be more confident of the quality of their findings and the quality of the simulation model which is based on the data that was collected (5:175).

After a cursory examination of the Work Request/Work Order Log beginning 1 February 1977, it was obvious that many of the work requests logged in as having been received on 1 February 1977 represented requests which had actually been received some unknown time prior to the official reorganization date. In addition, the list of AF Forms 332 sent back as being unacceptable was not maintained by Customer Service after 28 February 1979. These two factors, plus the knowledge that more recent requests would show a lowered proportion of requests on which a disposition had been determined and a lowered proportion of requests which had traversed the system, led the researchers to limit the search for data to the two-year period of 1 March 1977 through 28 February 1979.

Data was collected and tabulated into three separate data tables: (1) Work Requests Received/Disposition; (2) Work Request Sample Data; and, (3) Work Order Data.

Work Requests Received/Disposition Data

The Work Request/Work Order Log and the list of unacceptable AF Forms 332 were used to develop the tabled Work Requests Received/Disposition Data shown in Table 2. The purpose of collecting this data

MONTH RECEIVED *	TOTAL RECEIVED	SENT BACK	LOGGED-IN/SENT BACK OR CANCELLED	NOT YET DETERMINED	DISAPPROVED	CONTRACT	JOB ORDER	WORK ORDER
Mar '77	78	6	12	2	6	3	22	27
Apr	59	10	9	1	6	7	10	16
May	91	10	11		10	12	19	29
Jun	81	12	6		9	8	25	21
Jul	43	10	2	1	3	1	11	15
Aug	52	2	8		4		21	17
Sep	42	13	2		2	2	10	13
Oct	42	12	4	1	1	1	9	14
Nov	49	17	3		1	3	12	13
Dec	51	11	2	1	6	2	18	11
Jan '78	48	10	6		6	2	11	13
Feb	58	14	2	1	4	5	12	20
Mar	60	15	1	1	3	5	22	13
Apr	49	12	1	1	5	2	18	10
May	40	18	3	4	3		6	6
Jun	47	14	1		2	5	12	13
Jul	34	5	1	3	1	3	6	15
Aug	61	12	5	1	1	4	20	18
Sep	55	7	5	7	5	7	6	18
Oct	49	6	4	4	2	5	12	16
Nov	61	8	7	5	4		19	18
Dec	37	5	4	3	2	2	11	10
Jan '79	44	4	1	5	3	4	19	8
Feb	36	9	1	4		1	8	13
Determined % Total	1222	242	101	0	89	84	339	367
	100.0	19.80	8.27	0.0	7.28	6.88	27.74	30.03
*Period of time covered represents 504 workdays (holidays and weekends are excluded)								

Table 2

Work Requests Received/Disposition Data

was for generation of statistics on arrival rates and probabilities of each of the possible dispositions which would be modeled.

Each work request entry in the log was evaluated for date of initial entry into the system and final disposition, then either placed into the table at the appropriate place or a decision was made not to consider the data. The data not considered was for one of the following reasons:

1. Although a separate log was maintained for self-help work requests, a total of 61 requests in this main Work Request Log showed self-help as the final disposition. Since requests accomplished by the self-help method of accomplishment are modeled as having not entered the system, data on these 61 requests were not considered.

2. A total of 51 requests were for purchase of materials only. These requests were considered by the researchers to be the equivalent of requests for self-help accomplishment; and the data was, therefore, not considered.

3. A total of 59 requests showed a different work request/work order number as the final disposition or otherwise indicated that the work was accomplished on the same job as some other request. Because there were no indications at what point in the processes the requests were merged, it was decided to model these requests as having not been received.

Dispositions as recorded in the log were frequently expressed in literal terms. Therefore, recording of the data required some interpretation by the researchers. For example, dispositions of "Sent back--Funds" were interpreted to mean disapproved because of lack of funds.

Dispositions of "Sent back" were interpreted to mean returned to requestor, either with concurrence of the requestor or asking for additional information; while dispositions of "Cancelled" were interpreted to mean returned to requestor at their request.

The remainder of the Work Requests Received/Disposition Data (Table 2) was acquired from the list of AF Form 332 work requests sent back prior to being entered on the Work Request/Work Order Log.

Work Request Sample Data

Data for supporting parameters concerning activity times in the work request portion of the system was collected primarily from the Work Request/Work Order Log, and was supplemented by the log of work requests maintained by the Planning Section. Since no records except log entries are maintained of requests which are disapproved, cancelled, or otherwise stopped short of work accomplishment, these two logs are the only documents which might reflect all requests which were found to be initially acceptable.

The amount of data needed to determine the parameters is represented by the following equation:

$$n \geq \left[\frac{\sigma \times Z_{\alpha/2}}{d} \right]^2$$

where:

n = sample size

σ = estimate of the variance

Z = value for area from normal distribution tables for $\alpha/2$ confidence level

d = detection difference in the same units as the variance

The above formula was used to estimate the sample size necessary to estimate the parameters of the work request/work order receipt rate within four requests with a confidence level of 99.5 percent. The number of requests per month ranges from 91 to 34. The sample size is 104 which is calculated below.

$$n \geq \left[\frac{\frac{(91 - 34)}{4} \times 2.860}{4} \right]^2 \geq 104$$

The Work Request/Work Order Logs at Barksdale were arranged by work category within each fiscal year. Since this arrangement grouped requests into large categories, a systematic sampling plan was adopted to insure representative sampling within each category. Every tenth work request was selected, to exceed the required sample size.

In implementing the sampling plan, the researchers made a random start at one of the first ten log entries for self-help work beginning 1 February 1977 and selected every tenth work request logged in. After the decisions were made to model self-help requests as having not entered the system, 51 sampled requests which had been collected from self-help portions of the logs, and five other sampled requests which showed disposition of self-help which had been collected from the Military Family Housing portion of the logs, were eliminated from this data file. In addition, data on four requests which had been received prior to 1 March 1977 and on five requests which had been received after

28 February 1979 was also eliminated from this data file, leaving data on the 114 work requests shown at Appendix B.

Data collected for this file included dates that the selected work requests were logged as being received, sent to Planning, received from Planning, sent to Engineering and Environmental Planning (DEE), received from DEE, sent to Production Control Center (PCC), received from PCC, sent to Resources and Requirements (R & R), received from R & R, received approved or disapproved in the Customer Service Unit (CSU), and sent to Scheduling. In addition, the disposition of each request was recorded. Dates that these requests were logged as being received and sent out of Planning and the number of Planning Section man-hours used in evaluation of each request were recorded from the log maintained by the Planning Section. Dates that work requests were logged into and out of the Planning Section were used in place of dates from the Work Request/Work Order Log where such dates were available.

The dates recorded from the various source documents were of varying forms, which would have been difficult to analyze by computerized analysis. Therefore, all dates were converted to numbered workdays within the two-year period of interest. 1 March 1977 was treated as day 1, 2 March 1977 was day 2, etc. Weekends and holidays were not numbered. The conversion calendar is included as Appendix C. There were a total of 504 working days in this two-year period.

Work Order Data

Data for supporting parameters concerning activity times in the work order portion of the system was collected from many sources. In-service work orders for which requests had been received after 1 March

1977 and for which work had been completed by 28 February 1979 were identified by inquiries into the Base Engineer Automated Management System (BEAMS) against the current Work Order History Tape, the Work Order History Tape for October 1977 through September 1978, and the current Work Order Master File. These inquiries provided Work Order Number, Work Class, Work Order Indicator, Special Interest Code, Number of Shops, Estimated Shop Labor Hours, Actual Shop Labor Hours, Estimated Material Cost, Actual Material Cost, Date Opened, Date Materials Available, Actual Start Date, and Actual Completion Date. This data was collected by this method for 229 work orders.

An additional 30 work orders were identified as meeting the criteria on the list of actual completion dates maintained by the Scheduler. Data similar to that obtained through the inquiries was obtained for 28 of these 30 work orders from the Completed Work Order Cost Reports found in the Work Order Folders. Work Order Folders could not be located for the other two work orders.

Other data was searched for and recorded from the following sources for all 259 work orders shown at Appendix D. From the Work Request/Work Order Log were recorded: Date Received, Dates to and from DEE, Dates to and from Other, and Date to Scheduling. From the Planning Work Order Log the Dates Logged In and Out and the Number of Planning Man-Hours required for planning the job were recorded. From the Work Order Folders: Priority and Date Authorized were obtained from the AF Forms 327; the Request Source (either AF Form 1135 or AF Form 332), the Approval Authority and the Date of Approval were obtained from the source document; Material Order Date was recorded from the AF Form 1445;

and, the date all materials were available was recorded from a slip of paper known at Barksdale as the 100% Slip. From the logs maintained in Material Control were recorded the dates that the work order folder was received from and returned to Scheduling each time the folder went to Material Control. From the list of work orders sent to Material Control, maintained by the Scheduler, were recorded dates that the work orders were sent. From the list of work order completion dates maintained by the Scheduler were recorded the completion dates.

Dates from the log maintained by Planning were used when available in place of dates from the Work Request/Work Order Log, and dates of work completion from the Scheduler's Log were used in place of Actual Completion Dates from computer printout because they were believed to be more accurate because of frequent delays in making the required computer entries.

Dates from this data collection were converted to numbered work-days according to the conversion calendar at Appendix C.

DATA ANALYSIS

After the data was collected, it was analyzed to determine the mathematical relationships between the processes in the system and between the processing times experienced at each processing point. Also, the attributes, or characteristics, of the work request/work order, such as the time of arrival of the transaction to the system, were determined.

Work Requests Received/Disposition Data

The Work Requests Received/Disposition Data shown in Table 2 was analyzed to provide overall probabilities of work requests being

disposed of through each of the categories. For accomplishing this analysis, the 45 requests found whose disposition has not yet been determined were not included in the calculations. These probabilities of work requests being disposed through each category are shown at the bottom of Table 2.

The total number of work requests received was used to calculate an average interarrival time, or average time elapsed between arrivals, of work requests to the CSU at the beginning of the system. The data represents a period of 504 working days in which a total of 1267 work requests were received. Simple division of the number of working days by the number of arrivals gives a mean interarrival time of 0.398 days, or one work request arriving every 0.398 days.

Work Request Sample Data

The Work Request Sample Data was analyzed by use of the Statistical Package for the Social Sciences (SPSS) computer program. SPSS is an integrated set of computer programs designed for the manipulation and statistical analysis of data. Included in this package are procedures for various types of regression and simple descriptive statistics (7:1).

SPSS subprogram FREQUENCIES was used to analyze the recorded dispositions. Since this data is nominal, no higher analysis was used. The results of this analysis corresponded almost exactly with the dispositions found in the Requests Received/Disposition Data. FREQUENCIES is used to examine the distributional characteristics of the variables being investigated. It calculates descriptive statistics and generates tabular reports of frequency distributions. Also are provided the mean,

mode, minimum, and maximum variance of the data (7:7).

Differences in dates recorded between steps in the usual processing sequence were calculated using a FORTRAN computer program. The usual processing sequence was determined to be the following order: received, to planning, from planning, to DEE, from DEE, to PCC, from PCC, to R & R, from R & R, to CSU, to Scheduling. Where either date was unavailable, and where differences were negative, computations were not attempted. In addition, because of the high number of requests which did not follow this usual processing procedure, computations were made of the differences in dates experienced by the requests in being logged as Received and the next available date, and from the last available date to CSU. The results of the computations of dates differences were analyzed by use of SPSS subprogram CONDESCRIPTIVE, which calculates "common measures of central tendency and dispersion for interval-scale variables that assume a large number of values [7:7]." Variables that can assume a continuum of values are appropriate for CONDESCRIPTIVE analysis. The results of the CONDESCRIPTIVE analysis which became a part of the model are tabulated in Table 3.

Work Order Data

The Work Order Data shown in Appendix D was also analyzed by use of the SPSS computer program, but the analysis was accomplished in a step-by-step sequence in much the same sequence that the data elements would be determined or become known in operation of the actual system.

When a work request is received by CSU, any Special Interest (SI) in that request and the Work Class (WC) of the requested work are readily apparent to an experienced Customer Service Specialist. Subprogram

Data Element	Number of Observations	Mean	Range	Standard Deviation
Planning Man-hours	38	3.842	0-15	3.484
Received to Planning	50	1.180	0-11	2.087
To and from Planning	49	3.163	0-36	6.219
To and from DEE	12	33.417	0-162	48.254
To and from PCC	0	0	0	0
To and from R & R	13	3.923	0-24	7.533
To CSU to Scheduling	35	1.143	0-17	3.751
Received to next	105	.571	0-11	1.550
Last to CSU	89	3.416	0-85	11.482

Table 3

CONDESCRIPTIVE--Work Request Sample Data

FREQUENCIES was used to evaluate the relative frequency of occurrence of each of the SI codes and each of the work classes. These codes were not known for two of the 259 work orders. The frequencies found for the SI codes are shown in Table 4.

<u>SI</u>	<u>Code</u>	<u>Frequency</u>	<u>Relative Frequency</u>	<u>Cumulative Frequency</u>
Blank	0	164	63.8	63.8
Command Interest	1	42	16.3	80.1
Fire Deficiency	2	16	6.2	86.3
Hospital Support	3	12	4.7	91.0
SAF Project	4	4	1.6	92.6
Communications Support	5	7	2.7	95.3
Weapons Storage Area	6	8	3.1	98.4
Dorm Rehab Program	7	2	0.8	99.2
Bomb Comp Support	8	2	0.8	100.0
Missing		<u>(2)</u>	<u> </u>	
TOTAL		257	100.0	

Table 4

Special Interest (SI) Code Frequencies

SPSS subprogram CROSSTABS was run to tabulate the relative frequencies of occurrences of each of the possible Work Classes given each SI code. SPSS procedure CROSSTABS permits a two-way to n-way cross-tabulation of variables. It produces two-way tables to display the joint frequency distribution of two variables and computes statistics based on these tables (7:7). A portion of the output from this computer program is shown at Table 5.

SI Code	COUNT		Work Class		M-C		ROW TOTAL
	ROW	PCT	IBLANK	MNT	RPR	M-C	
			1	1	2	3	
			0	1	2	3	
BLANK	0	1	18	37	27	82	164
			11.0	22.6	16.5	50.0	63.8
CMDINT	1	1	3	7	9	23	42
			7.1	16.7	21.4	54.8	16.3
FPDC	2	1	0	4	2	10	16
			0.	25.0	12.5	62.5	6.2
HOSP	3	1	6	4	0	2	12
			50.0	33.3	0.	16.7	4.7
BAF	4	1	0	4	0	0	4
			0.	100.0	0.	0.	1.6
COMM	5	1	1	1	0	5	7
			14.3	14.3	0.	71.4	2.7
WSA	6	1	0	1	0	7	8
			0.	12.5	0.	87.5	3.1
DORM	7	1	0	0	0	2	2
			0.	0.	0.	100.0	0.8
BOMRCOMP	8	1	0	0	0	2	2
			0.	0.	0.	100.0	0.8
COLUMN			28	58	38	133	257
TOTAL			10.9	22.6	14.8	51.8	100.0

Table 5

CROSSTABS--SI Code by Work Class

SPSS subprogram CROSSTABS was also used for three-way analysis of frequencies of Priority with each combination of SI and Work Class and frequencies of Number of Shops with each combination of SI and Work Class. These eighteen tables are not included, but their use is described in Chapter 4.

SPSS subprogram REGRESSION was used to analyze Estimated Man-hours, Estimated Materials, Planning Man-days, Total Time in Planning, Total Time in Material Control, Time between Material Control and Actual Work Start, and Time between Work Start and Work Completion.

SPSS REGRESSION procedure is used for multiple regression calculations which allow the researcher to study "the linear relationship between a set of independent variables and a dependent variable while taking into account the interrelationships among the independent variables. The basic goal of multiple regression is to produce a linear combination of independent variables which will correlate as highly as possible with the dependent variable [7:8-9]." This linear combination can then be used to predict values of the dependent variable. Stepwise multiple regression was used, allowing the computer program to bring into the equation at each step the remaining variable which served to explain the largest portion of the as yet unexplained variation.

The output of these regression analyses is a series of factors which can be used in a regression equation of the form:

$$Y = A + B_1X_1 + B_2X_2 + \dots + B_kX_k$$

where Y is the dependent variable, A is the Y intercept, the B_i are regression coefficients, and the X_i are the independent variables. Each B_i represents the expected change in Y with the addition of one

unit of X_1 while the quantity of all other X_i are held constant (7:328-330).

A portion of the data collected is nominal data, in that each value is a distinct category and the value itself serves merely as a label or name for the category. No assumption of ordering or distances between categories is made. For instance, the Work Class and the Special Interest code are nominal variables. In such cases, the counting of members in each category is the only possible arithmetic operation that can be used (7:4). When used as a regression, each possible label must be treated as a separate variable which is either present ($X_i = 1$) or absent ($X_i = 0$) in the equation.

One of the outputs of multiple regression is the R^2 statistic. This statistic indicates the proportion of variation explained by the independent variables included in the regression equation. Another output from multiple regression is the standard error. The standard error statistic indicates that, on the average, the value of the dependent variable will deviate from the actual value by that particular number of units (7:331).

Following is a description of how multiple regression was used to develop the regression equations for the variables "Estimated Man-hours," "Estimated Materials," "Planning Man-days," "Planning Time," "Material Control Time," "Time to Start," and "In Progress Time." The researchers chose the lowest standard error as the basis for the best regression equation in each case.

Estimated Man-hours was regressed against Number of Shops and individual Work Class and SI code. The resulting coefficients, constant,

standard error, and R^2 are shown in Table 6.

Dependent Variable = Estimated Man-hours	Analysis of Variance	DF
R Square = 0.2950	Regression	8
Standard Error = 127.5508	Residual	248
--Variables in the Equation--		
Variables	B	Standard Error B
Number of Shops	36.8496	5.3001
SI (Command Interest)	89.4413	22.2288
WC (Repair)	97.2647	23.3075
WC (Maintenance)	40.8196	20.2109
SI (Weapons Storage Area)	91.9906	46.6938
SI (Eighth Air Force)	111.4747	66.5554
SI (Bomb Competition)	141.4610	91.3864
SI (Communication)	68.7316	49.6720
(Constant)	-6.3595	
Legend:		
WC = Work Class		
SI = Special Interest		

Table 6

Regression--Estimated Man-hours on Work Class,
Special Interest Code, and Number of Shops

Estimated Materials was regressed against Number of Shops, Estimated Man-hours, and each Work Class and SI code. The resulting data is shown in Table 7.

Dependent Variable = Estimated Materials		Analysis of Variance	DF
R Square	= 0.1977	Regression	6
Standard Error	= 1894.5298	Residual	250
--Variables in the Equation--			
Variables	B	Standard Error B	
Estimated Man-hours	6.0976	0.9288	
WC (Maintenance)	863.3730	300.5993	
Number of Shops	-185.8713	85.4277	
SI (Eighth Air Force)	-1773.1925	993.5732	
WC (Repair)	434.8407	353.7728	
SI (Command Interest)	-344.6478	335.8891	
(Constant)	475.9245		

Table 7

Regression--Estimated Materials on Work Class,
Special Interest Code, Number of Shops,
Estimated Man-hours

Planning Man-days was computed within the SPSS REGRESSION program to be Planning Man-hours divided by eight hours per day. Planning Man-days was then regressed against Number of Shops, Estimated Man-hours, Estimated Materials, and each Work Class, SI code, and Priority. The resulting data is shown in Table 8.

Dependent Variable = Planning Man-days	Analysis of Variance	DF
R Square = 0.2410	Regression	9
Standard Error = 0.8596	Residual	247
--Variables in the Equation--		
Variable	B	Standard Error B
Priority 1	1.5596	0.3714
Number of Shops	0.0663	0.0387
WC (Maintenance)	-1.3366	0.1402
SI (Weapons Storage Area)	0.7448	0.3153
SI (Bomb Competition)	-1.7235	0.6936
Estimated Man-hours	0.0008	0.0004
Priority 4	-0.5476	0.2414
Priority 3	-0.4443	0.2082
Priority 2	-0.2977	0.1975
(Constant)	0.9173	

Table 8

Regression--Planning Man-days on Number of Shops, Estimated Man-hours, Estimated Materials, Work Class, Special Interest Code, and Priority 1 through 4

Planning Time was computed by a FORTRAN program to be the difference in dates between the date logged To Planning and the date logged From Planning when the work orders went to Planning for planning (as opposed to going to Planning for evaluation in the Work Request stage). This Planning Time was regressed against Number of Shops, Estimated Man-hours, Estimated Materials, Planning Man-days, and each Work Class, SI code, and Priority. The resulting data is shown in Table 9.

Dependent Variable = Planning Time		Analysis of Variance	DF
R Square	= 0.1510	Regression	5
Standard Error	= 14.3329	Residual	182
--Variables in the Equation--			
Variable	B	Standard Error B	
SI (Dorm Rehab)	69.6910	14.5261	
Planning Man-days	2.6297	1.1641	
Priority 2	4.4593	2.2525	
WC (Minor Construction)	-2.9921	2.2197	
SI (Command Interest)	3.3375	3.3025	
(Constant)	3.0417		

Table 9

Regression--Planning Time on Number of Shops, Estimated Man-hours, Estimated Materials, Planning Man-days, Work Class, Special Interest Code, and Priority 1 through 4

Material Control Time was computed by a FORTRAN program and is the difference in dates between the time first logged in at Material Control and first logged out of Material Control. This Material Control Time was regressed against Number of Shops, Estimated Materials, and each Work Class, SI code, and Priority. The resulting data is shown in Table 10.

Dependent Variable = Material Control Time		Analysis of Variance	DF
R Square	= 0.1842	Regression	13
Standard Error	= 54.8301	Residual	185
--Variables in the Equation--			
Variable	B	Standard Error B	
WC (Maintenance)	-10.2961	15.5284	
SI (Command Interest)	-36.7407	13.5489	
Estimated Materials	0.0041	0.0038	
Priority 1	-87.2948	27.5056	
WC (Repair)	38.6771	17.7801	
WC (Minor Construction)	20.8784	14.4578	
SI (Communication)	-50.4506	29.1215	
Number of Shops	2.8997	2.6052	
SI (Fire Protection)	19.4910	16.1604	
Priority 2	-38.8464	19.5423	
Priority 4	-44.1655	23.6727	
Priority 3	-27.9634	20.0759	
SI (Hospital)	-21.5572	18.5348	
(Constant)	87.1651		

Table 10

Regression--Material Control Time on Number of Shops, Estimated Materials, Work Class, Special Interest Code, and Priority 1 through 4

Time to Start was computed by a FORTRAN program to be the difference in Start Date and the last date out of Material Control if the work order went to Material Control, or the Date Authorized if the work order did not go to Material Control. Time to Start was regressed on Number of Shops, Estimated Man-hours, Estimated Materials, and each Work Class, SI code, and Priority. The resulting data is shown in Table 11.

Dependent Variable = Time to Start		Analysis of Variance	DF
R Square	= 0.1164	Regression	8
Standard Error	= 48.8001	Residual	190
--Variables in the Equation--			
Variable	B	Standard Error B	
SI (Communication)	70.9451	22.3159	
Priority 3	22.0761	8.2760	
WC (Minor Construction)	24.0900	11.5991	
WC (Repair)	21.4988	14.0065	
WC (Maintenance)	15.0425	12.8915	
SI (Command Interest)	-16.3056	11.9767	
Estimated Man-hours	0.0585	0.0410	
Estimated Materials	-0.0019	0.0017	
(Constant)	9.2613		

Table 11

Regression--Time to Start on Number of Shops, Estimated Man-hours, Estimated Materials, Special Interest Code, Work Class, and Priority 1 through 4

In Progress Time was computed by a FORTRAN program to be the difference in Start Date and Completion Date. In Progress time was regressed on Number of Shops, Estimated Man-hours, and each Work Class, SI code, and Priority. The resulting data is shown in Table 12.

Dependent Variable = In Progress Days		Analysis of Variance	DF
R Square	= 0.2546	Regression	8
Standard Error	= 31.5650	Residual	248
--Variables in the Equation--			
Variable	B	Standard Error B	
Estimated Man-hours	0.0912	0.0156	
SI (Command Interest)	15.2090	6.0620	
Priority 4	-33.4859	9.1851	
Priority 2	-25.5400	7.5250	
Priority 3	-25.6628	7.8496	
WC (Maintenance)	7.7709	5.1409	
Priority 1	-19.5028	12.6511	
Number of Shops	- 1.9816	1.4186	
(Constant)	34.9629		

Table 12

Regression--In Progress Days on Work Class (Maintenance),
Special Interest Code (Command Interest), Number of
Shops, Estimated Man-hours, and
Priority 1 through 4

SPSS subprogram CONDESCRIPTIVE was used in analysis of some of the differences in dates between processing points which were considered to be independent of the attributes of the work request/work order being processed. These date differences were computed through use of a FORTRAN computer program prior to SPSS analysis. The variables analyzed and some of the descriptive statistics output are summarized in Table 13. Cases in which either of the data elements were missing or where the recorded dates reflected a negative difference (where the work request/work order had been processed in other than the evaluated sequence) were treated as missing cases and were not included in computation of the statistics.

ESTIMATES MADE

The data collected and analyzed as described above provided evidence or guidelines for many of the parameters required for modeling the system. No data was available, however, for many other parameters required for modeling the system.

It was estimated by one of the three people who work in the Customer Service Unit at Barksdale that one of the Customer Service Specialists could easily process all work requests/work orders traversing the CSU.

It was estimated by the Chief of the Planning Section at Barksdale that six of the eight assigned planners are working on work requests or work orders at any given time, with the remaining two planners handling job orders and other tasks.

It was estimated by the Chief of the Engineering Design Section

Data Element	Number of Observations	Mean	Range	Standard Deviation
Received to next	208	2.260	0-140	12.396
To and from DEE	5	17.000	0-57	24.238
To and from Other	3	2.000	0-6	1.000
From Approval to Scheduling	216	3.394	0-98	11.230
From Scheduling to Planning	180	2.717	0-155	11.611
From Planning to Authorized	188	15.048	0-145	22.473
From Authorization to Material Control	192	3.422	0-225	17.666

Table 13

CONDESCRIPTIVE--Work Order Data

that an average of less than one engineer is actively engaged in conducting evaluations of work requests.

The data as collected and analyzed and the estimates made by personnel working in the system provided enough of the parameters of the system to begin to computerize a model of the system using the Q-GERT analysis program. The modeling process will be described in Chapter 4.

Chapter 4

MODELING THE SYSTEM

INTRODUCTION

This chapter is devoted to a description of how Q-GERT was applied to this study, as well as to a description of the Q-GERT methodology itself, including a description of the symbols used. Also described is the construction of the model.

Q-GERT SYMBOLS

As indicated in Chapter 1, Q-GERT methodology was used to provide the operational technology for this study of the BCE work request/work order processing system. A complete network of the work request/work order model is included in Appendix E.

Q-GERT uses a set of special symbols to represent the object system. A description of these symbols will follow; however, for a more detailed explanation of Q-GERT, the reader is referred to Modeling and Analysis Using Q-GERT Networks, 2nd edition, by A. Alan B. Pritsker.

Q-GERT uses an activity-on-branch network system in which a branch represents an activity that consumes time. Nodes are used to separate branches and are used to model milestones, decision points, and queues. A Q-GERT network consists of nodes and branches. Flowing through the network are items referred to as transactions. Transactions are directed through the network according to the branching charac-

teristics of the nodes. Transactions can represent physical objects, information, or a combination of the two. In this simulation, transactions represent work requests, some of which become work orders midway through the system. Different types of nodes are included in Q-GERT to allow for the modeling of complex queueing situations and project management systems. Activities can be used to represent servers of a queueing system, and Q-GERT networks can be developed to model series and parallel service systems. The nodes and branches of a Q-GERT model describe the structural phases of the system.

Q-GERT employs the following basic node types--SOURCE nodes, Q-nodes, STATISTICS nodes, and REGULAR nodes. A discussion of these basic node types follows.

The first type of node in a Q-GERT network is the start node or SOURCE node. Its purpose is to serve as the starting point for the network and to generate incoming transactions (5:4,22,46). The following figure (Figure 10) is one of the model's SOURCE nodes. SOURCE nodes do not require incoming transactions to be released the first time. The release of a node is the term used in Q-GERT to specify that an incoming transaction can pass through the node and be routed according to the characteristics of the node. The modeler specifies the number of incoming transactions needed to release a node and the number of subsequent incoming transactions required to release the node. The purpose of the mark node (M) is to mark the time at which a transaction is released from a node. The mark time assigned to the transaction is an attribute of the transaction and is used in the collection of statistics concerning the time required for a transaction to be

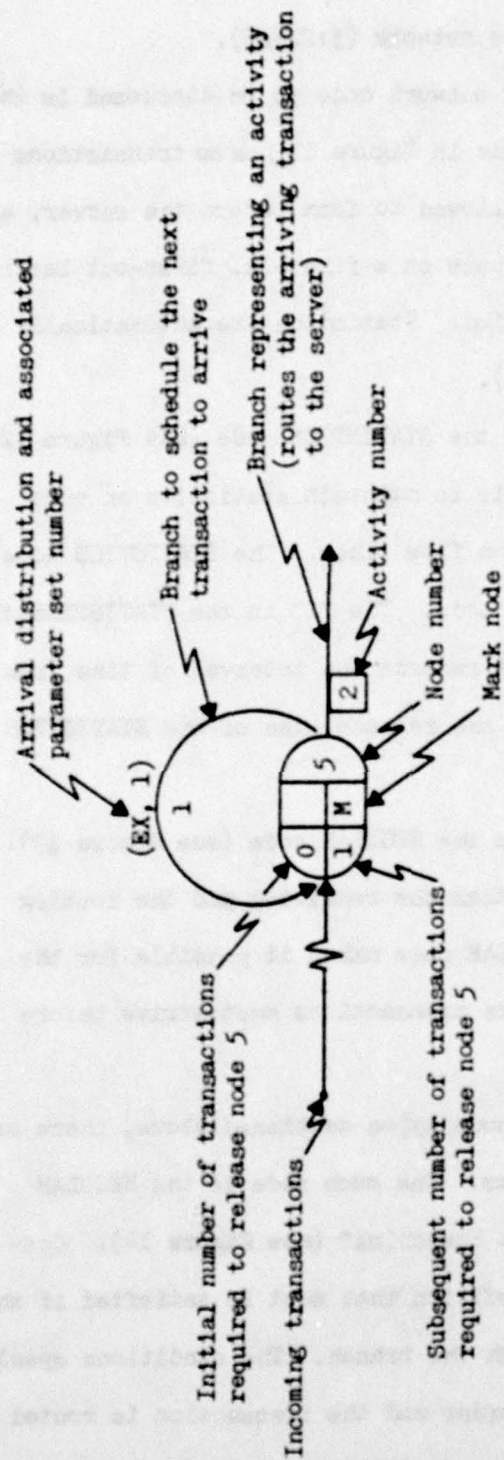


Figure 10
Source Node

processed through a portion of the network (5:22-25).

The second type of Q-GERT network node to be discussed is the Q-node (see Figure 11). The Q-node in Figure 11 has no transactions initially, an infinite queue is allowed to form before the server, and transactions will reside in the queue on a first-in, first-out basis. A Q-node represents a waiting period. Statistics are automatically collected on all Q-nodes (5:25,46).

The third type of node is the STATISTICS node (see Figure 12). The purpose of a STATISTICS node is to maintain statistics on node realization times or on transaction flow times. The STATISTICS node is organized the same as a SOURCE node. The "I" in the STATISTICS node indicates interval statistics. It records the interval of time from the marking of the transaction to the release time of the STATISTICS node (5:46,67).

The fourth type of node is the REGULAR node (see Figure 13). It has no special function other than the receiving and the routing of transactions (5:46). The REGULAR node makes it possible for the modeler to specify that two or more transactions must arrive before service can be provided (5:38).

In addition to the basic node types mentioned above, there are other types used in Q-GERT networks. One such node is the REGULAR node with "conditional--take first branching" (see Figure 14). Conditional branching specifies a condition that must be satisfied if the transaction is to be routed through the branch. The conditions specified on the branches are evaluated in order and the transaction is routed along the first branch for which the condition is satisfied. As soon

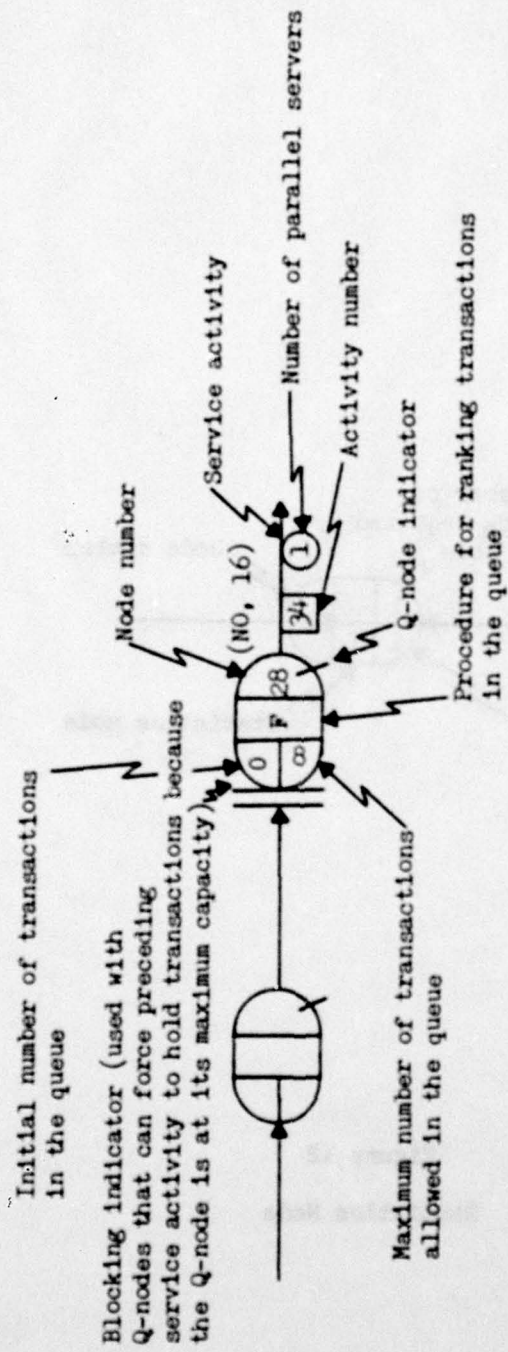


Figure 11

Q-Node

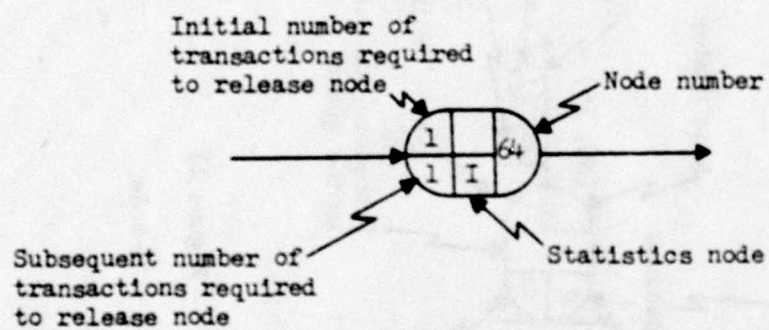


Figure 12
Statistics Node

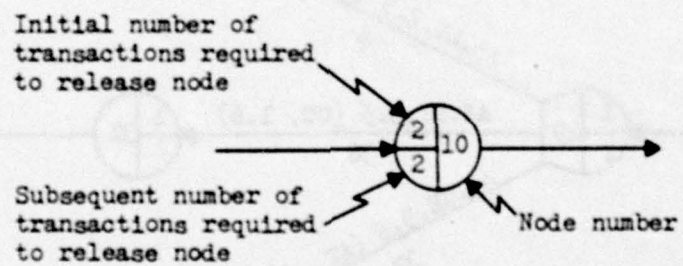


Figure 13

Regular Node

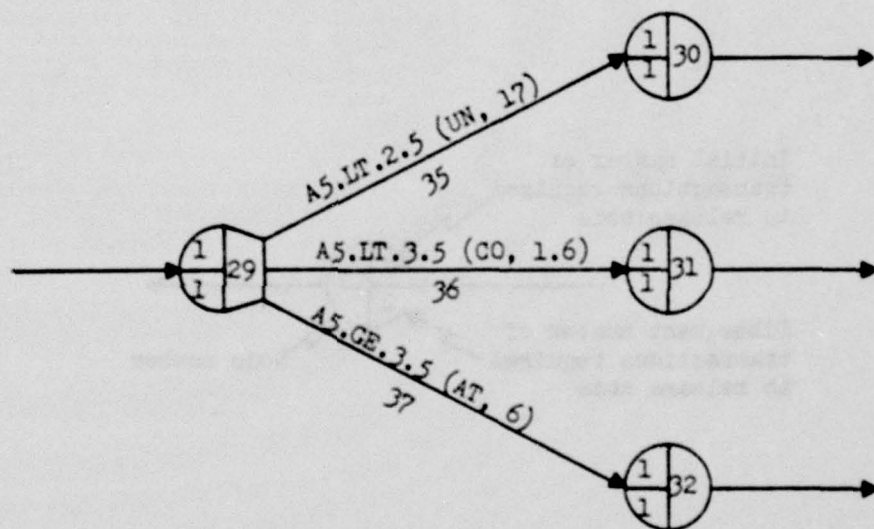


Figure 14

Regular Node with Conditional--Take First Branching

as one condition is found that is satisfied, the activity on that branch is scheduled, and the other conditions are not evaluated (5:145). In Figure 14, the condition specified on the branch from node 29 to node 30 indicates that the transaction should be routed through this branch if the value of attribute 5 of the transaction is less than 2.5 (A5.LT.2.5). If this is the case, the transaction is routed through activity 35 where it incurs a time delay, (UN, 17) uniformly distributed in accordance with parameter set 17, before it arrives at node 30. Once the transaction is routed to node 30, no further evaluations at node 29 would occur. If the value of attribute 5 for the current transaction is greater than 2.5, then the condition on the branch from node 29 to node 31 is evaluated. The condition specified here (A5.LT.3.5) indicates that the transaction should be routed through this branch if the value of attribute 5 of the transaction is less than 3.5. If this is the case, the transaction encounters a delay of 1.6 time units (CO, 1.6) and then is routed to node 31. If the transaction is routed to node 31, no further evaluation at node 29 will occur. If the value of attribute 5 is greater than 3.5, the condition on the branch from node 29 to node 32 is evaluated. The condition specified here (A5.GE.3.5) indicates that the transaction should be routed through this branch if the value of attribute 5 is greater than or equal to 3.5. This would occur with a delay of the number of time units indicated by the value of attribute 6 (AT, 6) for the current transaction.

Another node is the ALLOCATE node (see Figure 15). The ALLOCATE node is used to allocate resources to transactions that arrive to or are waiting in Q-nodes that precede the ALLOCATE node. Resources are

allocated when resources become available due to a transaction passing through a FREE or ALTER node (5:359-360).

The FREE node (Figure 16) is placed in the network where transactions can cause resources to be made available. The resource number and the units of the resource to be freed are prescribed. Other information associated with the FREE node is a list of ALLOCATE nodes to be polled in order to reallocate the resources freed at the FREE node (5:362-364).

The ALTER node (see Figure 17) is placed in the network at locations where it is desired for transactions to cause a change (positive or negative) in the capacity of a resource type. Each transaction that arrives to the ALTER node causes the same alteration in the resource capacity. Branching from an ALTER node can be done in the same manner as from a REGULAR node. A list of ALLOCATE nodes are prescribed for the ALTER node in the same manner as is done for the FREE node (5:364-367).

The model was essentially constructed to represent the flow of work requests and work orders experienced at Barksdale. When the nodes just described are combined with the distributions and regressions developed in Chapter 3, a network of the BCE work request/work order processing system was developed. See Appendix E for the Q-GERT network model of the system.

ANALYSIS OF Q-GERT NETWORK

The analysis of a Q-GERT network is performed by the Q-GERT Analysis Program on a digital computer. "The Q-GERT Analysis Program

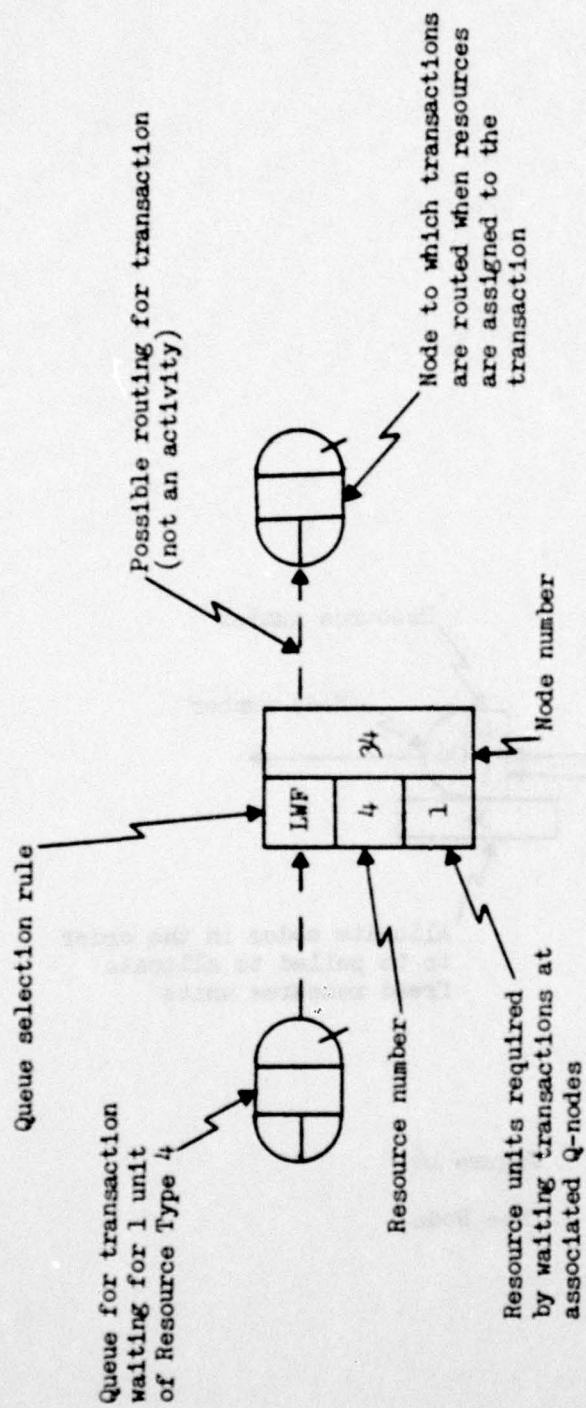


Figure 15
Allocate Node

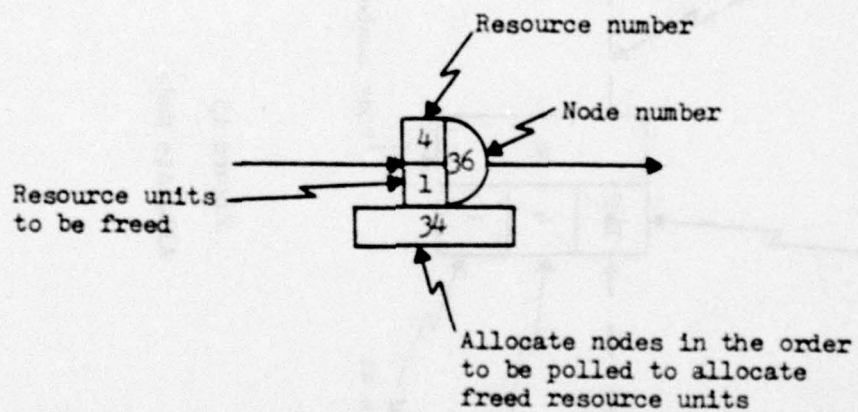


Figure 16

Free Node

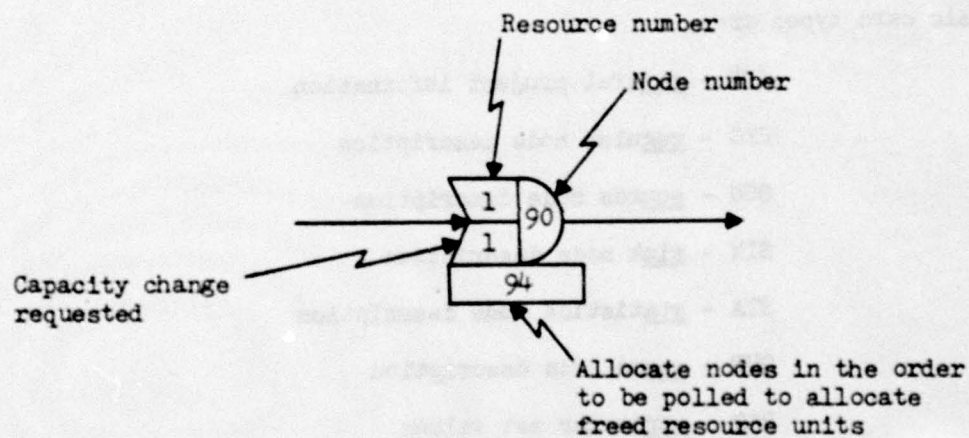


Figure 17

Alter Node

employs simulation techniques to analyze the flow of transactions through the network in order to obtain statistical estimates of the quantities prescribed on the Q-GERT network [5:52]." Through the use of specially coded data cards, the network is input into the computer for analysis. Each node, activity, and parameter set in the network requires a data card. In addition, special cards are required to identify attributes, identify resources, and to begin and end the program (5:52-53).

The data cards are identified with a three-character alphanumeric identification specified in the first field of the card. The basic card types are:

- GEN - general project information
- REG - regular node description
- SOU - source node description
- SIN - sink node description
- STA - statistics node description
- QUE - queue node description
- PAR - parameter set values
- ACT - activity description
- FIN - finish (signals end of input cards)

The node cards indicate the number of the node they refer to and then the specific data concerning the particular node are given. The GEN card is required to start the network and is used to identify general information about the network such as name of the modeler, the project name, the date, the number of statistics and sink nodes, and the time and number of runs. The FIN card is used to indicate the end of the

input cards. The Q-GERT Analysis Program employs distinct event procedures to simulate the flow of transactions through the network. Basically, only one type of event is included in the program: the arrival of a transaction at a node. The decision logic that can occur when a transaction arrives at a node is included in the program; and the appropriate actions, including the collection of statistical quantities, are taken based on the network model provided by the modeler (5:53-58). For a listing of the coded Q-GERT model see Appendix F.

In addition to the coded Q-GERT model, a user function was written in FORTRAN to supplement the model (see Appendix F). The use of this user written program insert allows the modeler to model specialized situations such as the BCE work request/work order processing system, which has many time related events and numerous distribution types and frequencies. The letters UF in the Q-GERT input are used to indicate that a user function is to be used at a branch or node. For example, Figure 18 indicates the user function number 2 (UF, 2) is to be called every time service activity 3 is started. The primary use of user function number 2 is to specify the performance time at activity 2. Additionally, other decision elements may be coded into

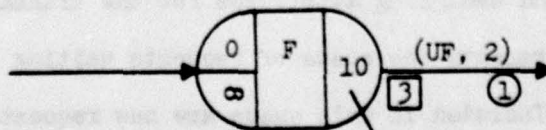


Figure 18

Calling of User Function

AD-A075 590

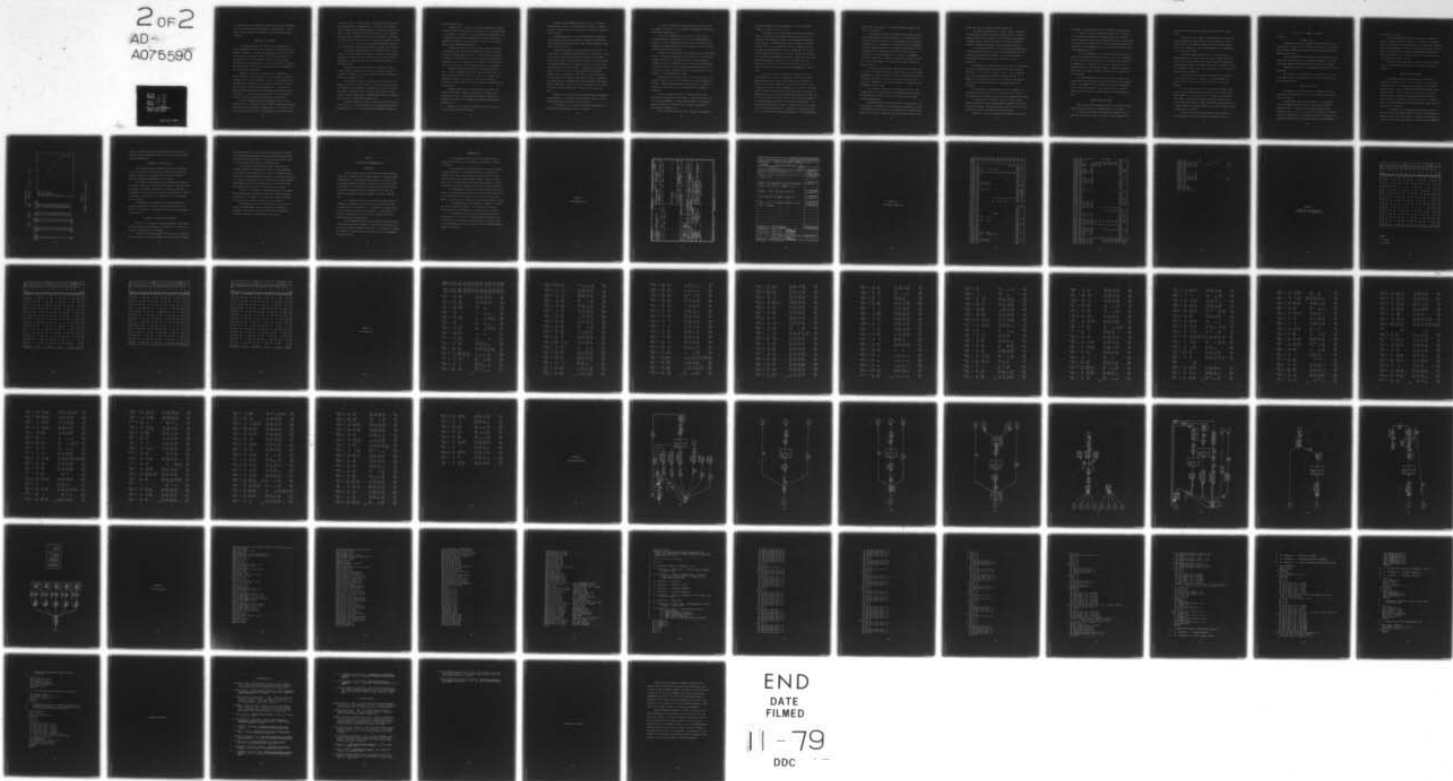
AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL--ETC F/G 13/2
A MODEL OF THE BASE CIVIL ENGINEERING WORK REQUEST/WORK ORDER P--ETC(U)
SEP 79 W A ARNOLD , D G FOGLEMAN
AFIT-LSSR-19-79B

UNCLASSIFIED

NL

2 OF 2

AD-A075590



the function such as the halting of ongoing activities, the reassignment of attribute values, and the modification of nodes (5:Ch.7). In this manner, various distributions required by the simulation model were identified.

CONSTRUCTION OF THE MODEL

The Q-GERT simulation model of the work request/work order processing system was constructed as shown in the Q-GERT network flow diagram at Appendix E. The model was essentially constructed to duplicate the flow of actual work requests and work orders experienced at Barksdale, but due to the limitations of time and computer space restrictions, many assumptions had to be made to streamline the network. These assumptions, as well as use of the data analysis from Chapter 3, will be discussed in this section.

Operation of the model is generated by the SOURCE node 1. Activity number 1, which loops back onto node 1, was used to generate subsequent arrivals of work requests at node 1. The interarrival rate was assumed to be exponentially distributed--the inverse of a Poisson arrival process. The mean used in parameter set 1 to describe this process was the mean taken from the Work Requests Received/Disposition Data (Table 2). Activity 2 calls User Function (UF) 1, providing for no delay to node 2 and assigning attributes for the transaction.

Q-node 2 represents the queue of requests waiting to be processed by the CSU. Included in this queue are new requests plus requests returning from being evaluated by Planning, DEE, or other experts. The CSU specialist selects requests to be processed on essentially a first-

in--first-out basis. Activity number 3 represents the processing time. This time, described by parameter set 2, was based upon the estimate that one server could process all requests. One server was used in the model. A normal distribution was assumed for lack of data to support any distribution. REGULAR node 3 was used to facilitate "conditional--take first branching" from CSU to one of six possible branches, to nodes 4, 5, 6, 7, 8, or 9. The Work Requests Received/Disposition Data was used to establish the probability associated with each of these branches.

Unacceptable requests were routed to STATISTICS node 4 with no delay. The routing criteria was based upon attribute 10 which had been assigned in UF 1 based upon the probability of any request being found unacceptable. Transactions are lost to the system upon arrival at STATISTICS node 4.

Requests that require an estimate by Planning were routed to Q-node 5, where the requests enter a queue of requests waiting to be processed by Planning. The routing criteria was based upon attribute 11 which had been assigned in UF 1.

Upon arrival at Q-node 5, transactions await allocation of a planner (Resource 4) at ALLOCATE node 34. When the allocation is made, the transaction moves immediately to REGULAR node 60 where the service time begins. This service time on Activity 9 was assumed to be log-normally distributed based upon the CONDESCRIPTIVE analysis of planning man-hours, which is described by parameter set 4.

Arrival at FREE node 61 frees the planning resource for reallocation at node 34. Activity 60 back to Q-node 2 requires time described by parameter set 14, also developed from the CONDESCRIPTIVE analysis,

minus the service time.

REGULAR node 6 is used for the routing of requests that require evaluation by DEE. This evaluation is Activity 6 and is routed according to the criteria of attribute 12. The DEE evaluation accomplishment time is lognormally distributed with parameter set 5 representing the processing time required to route the request to Q-node 2, and is based again upon the CONDESCRIPTIVE analysis.

Requests that require evaluation by some other section (other than Planning or DEE) are routed to REGULAR node 7 based on attribute 13 which has been assigned to Activity 7. After evaluation by others, the request is routed to Q-node 2, with an associated processing time (parameter set 6) that is assumed to be lognormally distributed based upon the one case found in the Work Request Sample Data (Appendix B).

Requests that have been cancelled by the user are routed to node 8. This is represented by Activity 8 and based on attribute 14. Once a transaction arrives at node 8 it is lost to the system. The assumption was made that cancellation usually occurs during the evaluation or approval phase, and this was modeled as happening between the two phases.

Requests remaining in the system are routed to Q-node 9 for approval by the Chief of Production Control (PCC) or Chief of the Customer Service Unit. Times required for approval, disapproval, or forwarding are assumed to be lognormally distributed as described by parameter set 7.

REGULAR node 10 is used for branching to node 11, 21, or 22 on the "conditional--take first" basis.

Requests above the approval authority of the PCC or Chief of CSU are routed to node 11. The decision rules of Table 1 in Chapter 3 were used to establish the value of attribute 7, upon which taking this branch is based.

Requests disapproved at this level are routed to STATISTICS node 21 based upon the value of attribute 9 which was developed from the Work Requests Received/Disposition Data. Requests approved at this level are routed to node 22.

Requests reaching Q-node 11 for approval by the Chief of R & R or the Chief of the Operations Branch are queued to await action. Since no work orders in the Work Order Data were recorded as having been approved by the Chief, Operations, only the Chief, R & R, was included in the approval sequence; but the approval limits of the Chief, Operations, were used as the decision rule. Transactions are released from Q-node 11 when the Chief, R & R, becomes available as modeled by ALLOCATE node 37. Availability of the Chief, R & R, is controlled by a clock at ALTER nodes 94 and 95. When the R & R Chief is allocated, the transaction moves to REGULAR node 62 where the service time begins. Arrival at FREE node 12 makes the R & R Chief available for other work. "Conditional--take first branching" occurs at node 12 like that at node 10.

Approvals by the BCE and by the Facilities Board are modeled in the same manner. At the completion of the approval chain, each transaction has been routed to either node 21 or node 22.

At STATISTICS node 21, statistics on time to disapproval are collected, and transactions are lost to the system.

At Q-node 22, transactions await processing by the CSU. They are served on Activity 28 in time assumed to be normally distributed and described by parameter set 2.

Node 23 is a REGULAR node and is used to facilitate "conditional--take first branching" from CSU to one of three branches (to nodes 24, 25, or 26) representing methods of work accomplishment. The probability associated with each of these branches is based on the Work Requests Received/Disposition Data.

Requests to be accomplished by job order are routed to STATISTICS node 24. The routing criteria was based on attribute 9, which had been assigned to Activity 29. Similarly, requests to be accomplished by contract were routed to STATISTICS node 25 with routing criteria based on attribute 9 for Activity 30. Transactions reaching nodes 24 or 25 are lost to the system. STATISTICS node 26 collects statistics on the requests to be accomplished by work order.

Transactions are routed from node 26 to node 27 by Activity 32. STATISTICS node 27 collects the interarrival rate of work orders to be completed. Approved work orders are routed from node 27 to Q-node 28 by Activity 33 which calls UF 2 to reassign values to attributes 9 through 14.

Q-node 28 represents the queue of requests that have been approved for accomplishment as work orders. A first-in--first-out rule is used by the Programmer to process the work orders. The processing time is represented by Activity 34 and is normally distributed in accordance with parameter set 21.

Node 29, a REGULAR node, was used to facilitate "conditional--

take first branching" from the Programmer to one of five possible branches, to nodes 30, 31, 32, 33, or 45.

Work orders (W.O.'s) that require an estimate by Planning are routed to Q-node 30 where the transactions enter a queue of W.O.'s waiting to be processed by Planning. The routing criteria was based upon attribute 9. ALLOCATE node 34 is used to allocate one planner (Resource type 4) to a transaction and route it to REGULAR node 35. From node 35, the transactions are routed to FREE node 36. The performance time for this activity (Activity 40) is given by attribute 9 and is based upon the REGRESSION of Man-days. FREE node 36, for every transaction arriving, will free one unit of resource type 4 for reallocation at node 34. The processing time back to Q-node 28 is given by attribute 10, which is based upon the REGRESSION of Planning Time.

Activity 36 is used to identify work orders that need to go through the Chief of R & R for authorization. Node 31 is a Q-node where requests enter a queue of requests waiting for authorization. The routing criteria was based upon attribute 12, which had been initialized to zero in UF 2 and is increased to 3.0 at node 30. ALLOCATE node 37 is used to allocate one unit of resource type 3 and route it to REGULAR node 38. From node 38, the transactions are routed to FREE node 39. The performance time for this activity (Activity 42) is assumed to be lognormally distributed based on the criteria of parameter 7. For every transaction arriving at node 39, it will free one unit of resource type 3 for reallocation at node 37. Attribute 9 is reassigned a value of -1.0 to prevent re-entry into the planning loop. The processing time

back to node 28 is assumed to be uniformly distributed based on the criteria of parameter 23.

Work orders that require the acquisition of materials are processed through Material Control (Q-node 32). The routing criteria to Q-node 32 is based on attribute 6. The processing time from Q-node 32 to REGULAR node 40 is assumed to be normally distributed following the criteria of parameter 25, and the processing time from REGULAR node 40 to REGULAR node 41 is represented by Activity 45 and is based on attribute 11, which was established in UF 2 based on the REGRESSION on Material Control Time. Further processing of the request, from node 41 to Q-node 28 is assumed to be uniformly distributed according to parameter set 22.

When materials are complete, transactions are routed from node 29 to Q-node 33 representing material complete status, where they await programming into the First Future Month (FFM) In-Service Work Plan (IWP). Transactions are queued in node 33 on the basis of biggest value of attribute 8, Precedence, first, which was assumed to be based upon the REGRESSION of Time to Start.

UF 4 is called by Activity 47 from node 33 to node 42. This UF keeps track of the number of man-hours programmed into the FFM IWP. When the FFM IWP is filled, Activity 47 is blocked by node 42, preventing overprogramming.

Releases from Q-node 42 occur when a unit of resource type 5 is made available. Availability of this resource is controlled by a clock at ALTER nodes 96 and 97, which allow the resource to be available once per month for 0.1 days. During this time, the contents of node 42 are

dumped into Q-node 45, representing Current Month IWP.

This same process is used with a weekly clock for establishing the weekly schedule, which is modeled as being released to the shop foremen at FREE node 48. Evaluation by the foremen is represented as a constant 2 days on Activity 50, based on the time from foremen's receipt of prescheduling packages to the prescheduling meeting.

At the prescheduling meeting some work orders are identified as requiring additional materials, some are not accomplishable for other reasons, and others are accomplishable. This is modeled through probabilistic branching from node 49 to nodes 28, 49, and 50, respectively.

The probability of branching to node 28 is based on the relative occurrence of ordering materials second and third times in the Work Order Data. UF 3 is called on Activity 53 back to node 28 which provides an estimated material reorder and a material leadtime. In addition, UF 3 increases attribute 12 to 5 so that the work order can re-enter the Current Month IWP when the reordered materials are available.

The probability of branching back to node 49 is based on an assumption made by the researchers. The constant activity time of 5 days represents reconsideration at the next week's prescheduling meeting.

The probability of branching to Q-node 50 is based upon the difference between 1.00 and the probabilities associated with the other two possible branches. The constant activity time to node 50 of 3 days represents the delay to the start of the following week.

Q-node 50 is a node where transactions await actual work start.

Here again, the highest precedence job is modeled as starting first.

Activity 54 is used to process transactions out of Q-node 50. UF 8 is called to calculate the processing time for this activity, which is computed by dividing the estimated man-hours by 16 and dividing the quotient by the number of shops. This formula was developed by the researchers to be representative of the time the shops would be blocked from starting the next job.

UF 8 also establishes a new value for attribute 14, which is used as the processing time for Activity 55. This activity represents the total time that the transaction is in the shops, and is based upon the REGRESSION on In Progress Days. Arrival at STATISTICS node 52 represents the end of the system as modeled. Interval statistics are here collected to provide information on total time in the system for the work orders.

The above description was a discussion of the completed work request/work order processing system model developed for this research effort. (See Appendix E for the Q-GERT model network and Appendix F for the coded Q-GERT program.) With the construction of the model completed, it was possible to make an attempt at operationalizing the model.

OPERATIONALIZING THE MODEL

With the model constructed as described in the previous section, numerous attempts were made at operationalization of the model.

Successful results were obtained when small portions of the model were simulated at a time, but neither the entire system nor the

entire work order portion of the system could be made to run without error.

The error codes encountered in these attempts were Q-GERT error type 14, "Insufficient space available to store attributes of transactions [8:438]," and Honeywell system error codes FO, Memory Address Fault, or Q6, Termination of Object Program Execution via FORTRAN Execution Error Monitor (FXEM).

The Q-GERT program does print a file of current events at program termination in cases such as this. Such a current events file shows the end time, end node, activity number, mark time, attributes, and transaction number of all ongoing activities at termination, as well as the transaction number, mark time, and attributes of all transactions in each Q-node at termination.

It was noticed that the number of transactions in the system at each termination was 106. These facts led the researchers on a search of Q-GERT literature to discover the limit which was being exceeded.

It was found that the limit on the number of concurrent transactions in the Q-GERT system is 400 (9:Table 1). This limit was not being exceeded, but it was later found in the same document that the array DESCR(.) "maintains the transaction attribute information and must be dimensioned such that (number of attributes per transaction + 1) * (maximum number of concurrent transactions) is less than the dimension of DESCR which is 1600 [9:3]."

Since the network as modeled assigned fourteen attributes to each transaction, the system as modeled was therefore limited to:

$$(14 + 1) * (MXTRS) \leq 1600,$$

therefore:

$$MXTRS \leq 106.$$

Investigation then was conducted into whether this limit could be extended. A telephone call to Pritsker & Associates, Inc., confirmed that the limit on DESCR could indeed be extended by redimensioning the Q-GERT object program (15).

While this procedure is relatively easy to accomplish, the time required for modification and for testing and "debugging" of the modified program exceeded the time limitations imposed on this research.

Therefore, the model was not successfully operationalized by the researchers.

The remainder of this chapter will be a discussion of how the methodology discussed in Chapter 2 needs to be conducted when the model can be operationalized.

VALIDITY OF THE MODEL

The validity of the model needs to be verified by use of the Chi-Square test for goodness of fit, of both the dispositions and the time in the system.

The disposition data to which the results of the simulation should be compared are shown in Table 2, Work Requests Received/Disposition Data. The simulation will produce histograms from STATISTICS nodes 4, 8, 21, 24, 25, and 26 which will show the observed frequency of realization. These frequencies should be compared as the sample data with the expected frequencies based on the percentages of

the total shown in Table 2.

The time in the system to which the results of the simulation should be compared are shown in Figure 19. This figure is a histogram typed in the format of the histogram which will be produced at STATISTICS node 52, and displaying data collected in the Work Order Data. The data reflects the frequencies of differences between Date Received and Date Complete when placed into 20 cells with upper bound of the first cell of 40 days and cell widths of 20 days.

The relative frequencies should be used to develop the expected number of work orders being completed in that range of days from the simulation.

SENSITIVITY OF THE MODEL

As described in Chapter 2, the sensitivity of the model to changes in the variables needs to be tested prior to use of the model as a prediction tool. Such sensitivity testing would involve first running the model n times to determine the variability between average completion times. Individual variables would then be altered by a controlled amount, and the results of simulation with the altered variable recorded. Statistical tests would then be run to determine whether the results were statistically significantly different from the results prior to alteration.

It is expected by the researchers that the sensitivity of the model will be directly linearly related to most of the processing time. Queued processes, however, are expected to display an exponential relationship as the service times approach a level which would saturate the

** NODE STATISTICS **

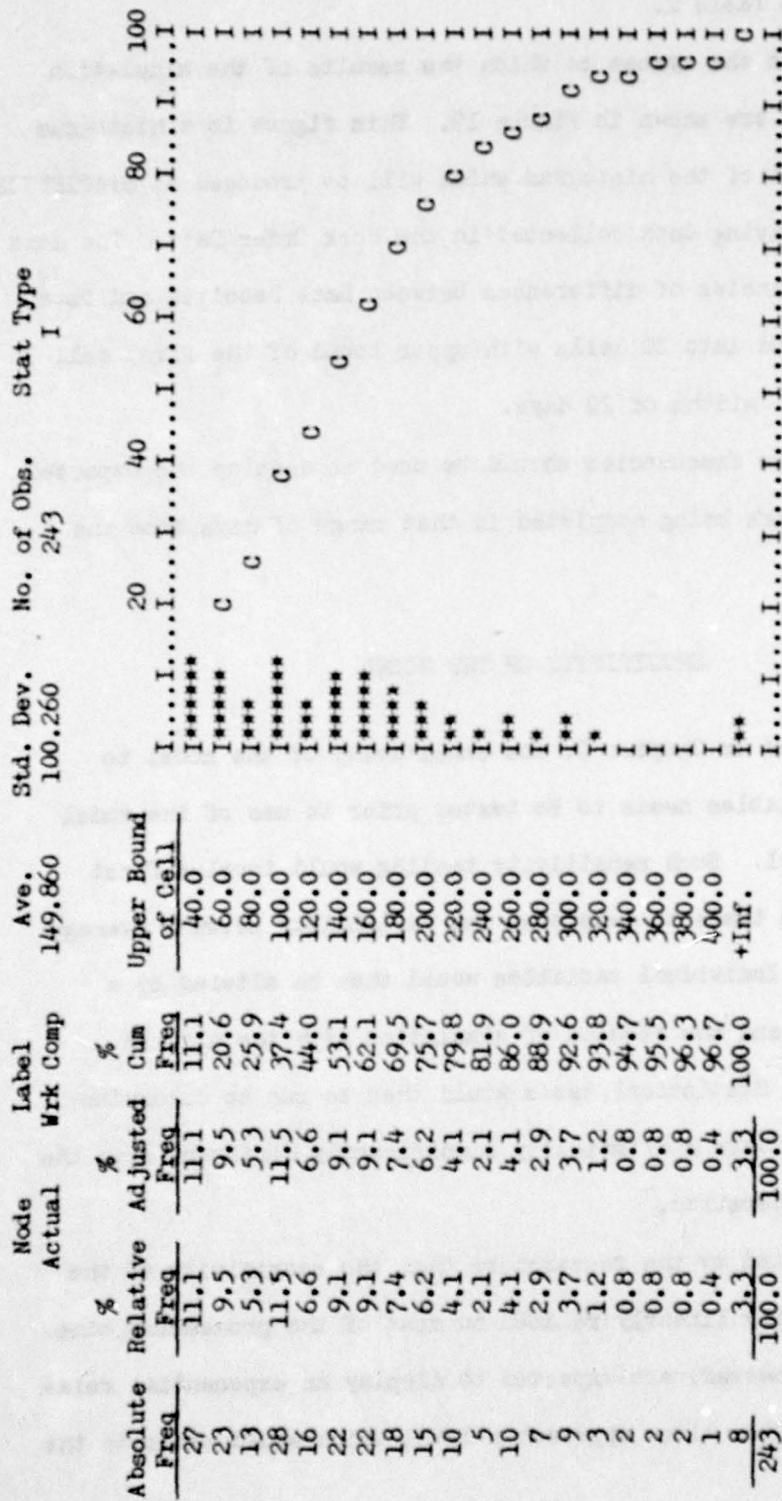


Figure 19

Histogram for Actual Time in System

servers. The same relationship would be produced if the number of servers at queued processes were reduced to a level below the average server utilization rate.

THE MODEL AS A PREDICTION TOOL

When the model has been internally and externally validated, the use of the model as a prediction tool should be evaluated. Prediction intervals can be established directly from the simulation results as shown below using Figure 19 as an example.

The confidence level required of the prediction must first be established, along with the portion of the interval in which error would be accepted. For example, using Figure 19, prediction intervals of approximately 80% confidence could variously be established as, "within 220 workdays," "between 40 and 300 workdays," and "not earlier than about 60 workdays."

The usefulness of such predictions should be evaluated by personnel working with the system. They should be evaluated on the basis of the usefulness of such predictions based upon the associated confidence level.

THE MODEL AS A CHANGE EVALUATION DEVICE

The utility of the model for predicting changes to the average processing times based upon changes to the system or to decision rules used in the system needs to be evaluated.

The effects of modeled changes will be shown in the simulation as node statistics for the work complete node, which shows the average

and standard deviation of total times in the system for work orders. The difference between statistics between simulations before modeling change and after modeling change will represent the predicted change to the processing times based upon the change modeled.

The accuracy of such predictions falls into the arena of external validity of the model, and may never be totally answerable. The accuracy of the prediction will, of course, be dependent upon how accurately the proposed change can be modeled. For example, a reduction in the number of planners from 6 to 4 could be modeled very accurately; but processing times for new processes may have to be modeled based upon estimates which may prove to be inaccurate in themselves.

The utility of the model for evaluating changes to the system will be dependent upon the degree to which field testing is replaced by simulation, or the degree to which productive changes which would not have been field tested or implemented can be evaluated.

With construction of the model completed, and with this discussion of further research which is required, this research is completed. The conclusions which are drawn from this research and recommendations made by the researchers are in Chapter 5.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

It was concluded that the work request/work order processing system can be described using the systems approach. The three primary subsystems are: (1) work request approval subsystem, (2) work order planning and materials acquisition subsystem, and (3) work accomplishment subsystem. The primary input variables to the system are number of requests, processing times and accomplishment time. When these variables are processed through the system, the output is completed work.

Even though the model was not successfully operationalized and validated, the researchers feel that the BCE work request/work order processing system can be simulated. It is basically a queueing system, and such systems lend themselves to simulation. It was further concluded that Q-GERT could be used to model and simulate the BCE work request/work order processing system.

A valid operational model of the work request/work order process could be used as an aid to estimation of the time to completion as well as a means to evaluate changes in the system. As an evaluator of changes in the system, the model would be most useful at the Civil Engineering and Services Center.

RECOMMENDATIONS

It is recommended that the limits of the Q-GERT program be extended and the model be run, validated, and evaluated as described in Chapter 4.

It is recommended that additional study be conducted to expand the model vertically to include areas which were excluded in this research effort, such as the in-service job order area and the self-help and contract work request processing areas. Inclusion of such areas into the modeled portion of the system will increase the utility of the model by providing meaningful statistics on server utilization.

It is recommended that future data collection gather more information on actual processing time for each service activity, rather than the total time which the transaction spent in travel, waiting, and service. Such data is more appropriate to the Q-GERT modeling technique.

It is recommended that future research be conducted to collect data from a representative sample of Air Force bases so that the resulting model can be generalized to be applicable Air Force-wide.

It is recommended that the resultant representative model be made available to the Air Force Civil Engineering and Services Center for use as a tool for making work completion time estimates for bases on an as-requested basis, and for use as a tool for evaluating proposed changes to the system.

APPENDIX A
WORK REQUEST FORMS

1. REQ. (Name and Address)		2. FROM: (Organization)		3. REQUESTER'S NAME AND PHONE NO.		4. WORK REQUEST NO.	
2 CES		2 SPS		Robert Wallis 6285		28656	
5. DATE OF REQUEST 15 JUNE 78		6. BUILDING OR FACILITY NO. 5050		7. REQUIRED COMPLETION DATE 1 DEC. 1978		8. OFFICE SYMBOL SPOL	
9. WORK REQUESTED		10. NOTIFICATION					
INSTALL DURESS ALARM SYSTEM IN THE SMALL ARMS STORAGE ROOM.		THIS DEVICE IS NEEDED TO PROVIDE ADDITIONAL PROTECTION TO SMALL ARMS STORAGE AREA.					
11. DONATED RESOURCES		12. NAME, GRADE, SIGNATURE OF OBSERVATION COMMANDER					
NONE		16 JUNE 78 605 <i>[Signature]</i> USAF					
13. COORDINATION (Office Symbol, Initials and Date)							
DEF 100 SE <i>[Signature]</i>							
FOR BCE USE ONLY							
16. WORK CLASS MC		17. INSTALLATION PRIORITY II		18. ESTIMATED HOURS 100		19. TOTAL ESTIMATED COST \$ 3750.	
20. ESTIMATED FUNDED COST \$ 1650.		21. WORK ORDER NO.		22. JOB ORDER NO.		23. BCE RECOMMENDATION	
24. METHOD OF ACCOMPLISHMENT <input type="checkbox"/> CONTRACT <input checked="" type="checkbox"/> IN-SERVICE		25. DATE SIGNED 19 Sept. 78		26. SIGNATURE BASE CIVIL ENGINEER <i>[Signature]</i>		27. ACTION TAKEN	
<input type="checkbox"/> DISAPPROVAL		28. ACCOMPLISHED BY <input type="checkbox"/> CONTRACT <input checked="" type="checkbox"/> IN-SERVICE		29. DATE SIGNED 22 Sept. 78		30. NAME, GRADE, TITLE AND SIGNATURE OF APPROVING AUTHORITY <i>[Signature]</i> USAF, COMINTASBCE	
<input type="checkbox"/> APPROVED		31. REMARKS					

BCE REAL PROPERTY MAINTENANCE REQUEST		Use to identify routine maintenance or repair requirements that do not meet the emergency criteria for a service call, or are not urgent in nature. Prepare and forward original and one copy to BCE for each facility on which work is requested.	
TO: Base Civil Engineering		FROM: (Name, Grade, and Organization)	
2 NOCES		Louis Colachi, MSCT, JSPS	
RETURN TO: (Office Symbol)		SPOL	
1. FACILITY NO. OR MPH STREET ADDRESS		2. PHONE NUMBER(S)	
5050		2814	
3. DESCRIPTION OF WORK REQUIREMENTS (A thorough description of maintenance requirement(s) will minimize the need for CE personnel to visit the job site to determine what work is requested and what tools, equipment, and materials are needed, thereby completing the work on the first attempt. Answer these questions: What? Where? How many? Type/size? Color? Rate? Urgency? Time restrictions?)		FOR CE USE ONLY	
REPLACE 24 SF. OF LIGHT BLUE 12"X12" FLOOR TILE IN ROOM 222		8. DATE RECEIVED 11 SEPT 1978	
		10. ACTION JOB ORDER #A5659 21 SEPT. 78	
REPAIR WALL (SHEETROCK), HAS BEEN DAMAGED BY WATER IN ROOM 241. APPROX 150 SF.		WORK ORDER NO. 15436	
RELAMP 12 EA. OUTSIDE FLOODLIGHTS		JOB ORDER #A5660 21 Sept 78	
LOCK BINDING ON DOOR TO ROOM 201		JOB ORDER #A5659 21 SEPT 78	
DOOR WILL NOT SECURE PROPERLY, WEST END ENTRANCE		JOB ORDER #A5659 12 SEPT 78 (URGENT) DIN	
4. DATE OF REQUEST		SIGNATURE OF REQUESTOR	
11 SEPT. 1978		Louis Colachi	
5. REVIEW/ACTION BY CUSTOMER SERVICE		DATE	
		11 SEPT. 78	
6. REVIEW/ACTION BY CHIEF PRODUCTION CONTROL		SIGNATURE	
		P. Bentley	
7. ASSIGNED FOR ACTION		DATE	
A. FUNCTION/INDIVIDUAL		SIGNATURE	
CS4 - BENTZ		Ed Hall	
8. CUSTOMER NOTIFIED		B. ACTION REQUIRED	
12 SEPT. 78		Cut WORK ORDER AND HAVE PLANNING CHECK ITEM #2	
		SIGNATURE	
		P. Bentley	

AF FORM 1135
MAY 78

PREVIOUS EDITION IS OBSOLETE.

APPENDIX B
WORK REQUEST SAMPLE DATA

WORK RQST. NUMBR	DAT REC	TO- PLN	NR HR	FRM PLN	TO- ENG	FRM ENG	TO- PCC	FRM PCC	TO- R&R	FRM R&R	TO- CSU	TO- SCH	D I S
21015	014								014	015	015		1
21025	018										018	024	2
21035	037	039		040	040	056					056		3
21045	048										048	048	2
21055	063	067	02	067	069	082	068	068	068	069	082		1
21065	075										075	075	2
21075	088										088		4
21085	105										105	105	2
21095	129										129		5
22008	166										166	166	2
22018	189	191	02	194							228		3
22028	213	213	02	213							214	228	2
22038	235										235	235	2
22048	246										246		6
22058	261	261	02	261							266	266	2
22068	285										285	285	2
22078	328										328	328	2
22088	341										341	341	2
22098	352										352	352	2
22108	369				370	371	369	369	369	370	371		3
22118	390										390	390	2
22128	391				391	410	391	391			410		3
23005	417												
23015	427											427	
50614	040										040	040	2
50624	057										057		5
50644	078										078		5
51001	172										172		5
51011	224				224	266					266		3
51021	384										384		5
61010	006	006		006							006		6
61020	045										045	045	2
62007	206	215		216							216		6
62017	316										316		5
62027	389										389	389	2
72098	002										002		5
72108	005										005		5
72118	009										009		6
72128	016										016		5
72138	023	026	04	029							032	032	2
72148	026	027		028	028	119					119		3
72158	035										035		5
72168	037										037		6
72178	041	041	04	041							041	041	2
72188	048	049	02	052							053		1
72198	053										053		5

104

72208	056	057	02	057		058	058		058		5		
72218	060								060	060	2		
72228	061				061	065	061	061	061	061	3		
72238	066	066		068	068	107	068	068	068	068	3		
72248	074	075		079	074	075					1		
72258	076								076		5		
72268	079	080		080					081	082	2		
72278	086	087	01	087					087	088	2		
72288	098	098	01	098					098		1		
72298	106								106		5		
72308	111								111		5		
72318	116	117		118					119	120	2		
72328	123	124	01	124					163		6		
72338	128	129	02	165					166		5		
72348	134	135	04	155					156		5		
72358	146								146		5		
73000	154								154		5		
73010	162								162		5		
73020	164	164	16	173							3		
73030	176								176	176	2		
73040	184								184		5		
73050	193								193		5		
73060	197								197		5		
73070	208								208	208	2		
73080	218								218		5		
73090	226	227	02	228					229	229	6		
73100	233	233	08	233					235	235	2		
73110	240	243	03	246							1		
73120	246	246	04	246		251	251	251	252	252	5		
73130	254								254		5		
73140	261					261	261	261	264	263	2		
73150	266								266		5		
73160	272	273	01	273					275	275	4		
73170	279	279	01	279					364	364	2		
73180	282								282		5		
73190	290	291	04	297					303	303	2		
73200	300	304	06	306	326	489	309	309	309	326	1		
73210	307	308	04	308					311		1		
73220	327	327	02	327	334	339	333	333	333	334	6		
73230	337								337		5		
73240	352	349	16	357					358		4		
73250	356	356	08	358		358	358	358	359	359	2		
73260	364	365	03	369					374		5		
73270	370	370		374					374		4		
73280	375	377	02	377					377		4		
73290	381								381		5		
73300	393	393		394	395	402	394	394	394	395	417	417	2
73310	396	397	04	399			400	400	400	400	400	400	2
73320	402	403	03	403			412	412	412	436	441	441	2
74002	404	404	02	411							414		

74012	409		409		
74022	414	415	04	416	
74032	420	420	03	424	
79000	429	429	02	429	
79013	432				
79023	436				
79033	437				
79043	443	443		443	
79053	447				
79063	453	464	08	468	
79073	457	457	06	473	
79083	468	468	04	473	
79093	475				
79103	476				
79113	484				
79123	487	487			
79133	493	493			
79143	503	504	01	505	

APPENDIX C

CALENDAR OF WORK ORDER DATES
(1 March 1977 - 28 February 1979)

MONTH DAY	1977										1978		DAY
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	
01	001	024	W	066	088	108	131	W	171	192	W	234	01
02	002	W	045	067	W	109	132	W	172	193	H	235	02
03	003	W	046	068	W	110	W	152	173	W	213	236	03
04	004	025	047	W	H	111	W	153	174	W	214	W	04
05	W	026	048	W	089	112	H	154	W	194	215	W	05
06	W	027	049	069	090	W	133	155	W	195	216	237	06
07	005	028	W	070	091	W	134	156	175	196	W	238	07
08	006	029	W	071	092	113	135	W	176	197	W	239	08
09	007	W	050	072	W	114	136	W	177	198	217	240	09
10	008	W	051	073	W	115	W	H	178	W	218	241	10
11	009	030	052	W	093	116	W	157	179	W	219	W	11
12	W	031	053	W	094	117	137	158	W	199	220	W	12
13	W	032	054	074	095	W	138	159	W	200	221	242	13
14	010	033	W	075	096	W	139	160	180	201	W	243	14
15	011	034	W	076	097	118	140	W	181	202	W	244	15

LEGEND:

W - Weekend

H - Holiday

MONTH DAY	1977										1978		DAY
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	
16	012	W	055	077	W	119	141	W	182	203	222	245	16
17	013	W	056	078	W	120	W	161	183	W	223	246	17
18	014	035	057	W	098	121	W	162	184	W	224	W	18
19	W	036	058	W	099	122	142	163	W	204	225	W	19
20	W	037	059	079	100	W	143	164	W	205	226	H	20
21	015	038	W	080	101	W	144	165	185	206	W	247	21
22	016	039	W	081	102	123	145	W	186	207	W	248	22
23	017	W	060	082	W	124	146	W	187	208	227	249	23
24	018	W	061	083	W	125	W	H	H	W	228	250	24
25	019	040	062	W	103	126	W	166	188	W	229	W	25
26	W	041	063	W	104	127	147	167	W	H	230	W	26
27	W	042	064	084	105	W	148	168	W	209	231	251	27
28	020	043	W	085	106	W	149	169	189	210	W	252	28
29	021	044	W	086	107	128	150	W	190	211	W		29
30	022	W	H	087	W	129	151	W	191	212	232		30
31	023		065		W	130		170		W	233		31

MONTH DAY	1978										1979		DAY
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	
01	253	W	296	318	W	360	383	W	424	444	H	486	01
02	254	W	297	319	W	361	W	403	425	W	464	487	02
03	255	276	298	W	340	362	W	404	426	W	465	W	03
04	W	277	299	W	H	363	H	405	W	445	466	W	04
05	W	278	300	320	341	W	384	406	W	446	467	488	05
06	256	279	W	321	342	W	385	407	427	447	W	489	06
07	257	280	W	322	343	364	386	W	428	448	W	490	07
08	258	W	301	323	W	365	387	W	429	449	468	491	08
09	259	W	302	324	W	366	W	H	430	W	469	492	09
10	260	281	303	W	344	367	W	408	H	W	470	W	10
11	W	282	304	W	345	368	388	409	W	450	471	W	11
12	W	283	305	325	346	W	389	410	W	451	472	493	12
13	261	284	W	326	347	W	390	411	431	452	W	494	13
14	262	285	W	327	348	369	391	W	432	453	W	495	14
15	263	W	306	328	W	370	392	W	433	454	473	496	15

1977											1978		
MONTH	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	
DAY													DAY
16	264	W	307	329	W	371	W	412	434	W	474	497	16
17	265	286	308	W	349	372	W	413	435	W	475	W	17
18	W	287	309	W	350	373	393	414	W	455	476	W	18
19	W	288	310	330	351	W	394	415	W	456	477	H	19
20	266	289	W	331	352	W	395	416	436	457	W	498	20
21	267	290	W	332	353	374	396	W	437	458	W	499	21
22	268	W	311	333	W	375	397	W	438	459	478	500	22
23	269	W	312	334	W	376	W	417	H	W	479	501	23
24	270	291	313	W	354	377	W	418	439	W	480	W	24
25	W	292	314	W	355	378	398	419	W	H	481	W	25
26	W	293	315	335	356	W	399	420	W	460	482	502	26
27	271	294	W	336	357	W	400	421	440	461	W	503	27
28	272	295	W	337	358	379	401	W	441	462	W	504	28
29	273	W	H	338	W	380	402	W	442	463	483		29
30	274	W	316	339	W	381	W	422	443	W	484		30
31	275		317		359	382		423		W	485		31

APPENDIX D
WORK ORDER DATA

WORK ORDER	W C	# S	EST. M.H.	EST MATL.	TO- PLN	TO- DEE	TO- OTH	FM- APP	TO- PLN	PL MH	IN- MC1	IN- MC2	IN- MC3	ST- ART
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DAT REC	S I	P R	ACT. M.H.	ACT MATL.	FM- PLN	FM- DEE	FM- OTH	TO- SCH	FM- PLN	DAT ATH	OUT MC1	OUT MC2	OUT MC3	CO- MPL
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21022	2	2	151	1533				017	018	08	030			247
017		3	151	1205				017	021	028	161			255
21023	2	2	285	1135				017	017	04	029			180
017		3	263	1290				017	019	026	120			252
21024	1	2	450	6500				008						079
018		3	398	6800				018		065				118
21025	1	2	340	0										141
018			433	0				018		023	023			436
21029	1	6	196	1210							033	117		286
021		3	216	1235				021		032	113	254		299
21030	3	6	136	0				021						418
021		3	89	0				021		026	028			428
21038	3	1	68	1879				034			040	162		118
039	1	2	44	2424				039		040	103	245		403
21039	1	2	280	18497										137
039		3	199	16128				039		041				143
21040	1	2	151	6515										131
		3	114	4891				039			124			139
21044	1	2	132	960				045	047	03				498
045		3	241	1350				045	048	051	455			521
21046	1	2	483	3341				049	050	06	124	418		440
049		3	590	4499				049	051	053	162	485		511
21047	2	2	195	2802	060	049					074			388
049		2	312	2508	066	060		067	071	074	314			408
21054	1	4	37	256				062			098			196
		3	50	172				062		096	129			199
21059	1	2	17	17				063	065					143
061		3	19	17				064	071	074	129			145
21063	1	3	322	1132				036	072					079
070	1	3	183	552				071		074	096			115

21065 2 4 1191 6427	075	108	144
075 1 3 764 3434	085 108 166	323	
21068 1 3 24 31	076 080 02 124	222	
077 4 16 28	076 084 120 157	223	
21073 2 2 62 105	081 090 08 124	192	
081 2 58 147	088 098 119 182	197	
21074 2 1 34 689	082	153	511
082 3 53 1407	082 152 494	522	
21078 1 1 120 1723	097 099 04 176	422	
097 2 59 2156	097 099 174 313	427	
21081 3 1 16 398	103 104 08 153	369	
103 3 44 392	103 109 152 338	394	
21083 1 160 1057	104 08 152	359	
103 3 115 1634	103 115 145 315	385	
21085 2 5 135 872	105 108 08 124	204	
105 2 146 688	105 114 120 173	212	
21086 1 4 228 1169	109	109	109
109 1 3 287 911	109 133 120	175	
21088 2 2 128 2058	112 114 08 145	256	
112 3 86 852	112 116 145 245	261	
21091 1 2 324 719	118 120 08 176	311	
118 3 248 651	118 123 174 267	327	
21093 1 2 198 30 120	123 126 08 153	281	
120 2 3 138 52 122	123 130 152 229	301	
21098 1 1 35 136	134	161	
134 3 29 107	134 140 158	196	
21100 2 2 100 1005	143 171 24 217	356	
143 2 60 796	170 181 211 357	385	
22001 3 7 255 1777	159 160 24 217	432	
159 3 450 2165	159 181 211 419	453	
22002 1 2 73 0	162 163 4	314	
162 3 35 0	162 163 164	316	
22003 1 6 172 1577	167 201	276	
166 3 250 1307	166 175 198 316	316	
22004 1 7 216 2195	167 201	276	
166 3 218 3028	166 175 198 316	303	

22005	1	7	235	1173	167		276
166	3	198	970	166	175	198 316	316
22006	1	5	96	834	167		277
166	3	196	563	166	175	198 316	323
22007	1	4	135	612	163	167 176	316
166	3	306	593	166	174	273	332
22010	2	3	228	1114	172	174 12 185	429
172	3	171	1307	172	177	184 420	443
22011	1	2	24	120	180	12 185	257
176	2	50	159	176	181	184 241	261
22015	1	2	72	818	185	186 04	320
185	2	114	371	185	186	317 329	331
22016	2	2	96	261	185	186 06 201	464
185	3	67	561	185	186	204 415	470
22017	1	2	81	17	189	189 8 193	301
189	3	97	10	189	189	192 259	312
22020	1	1	16	137	194	195 2 217	291
194	3	4	91	194	195	211 264	299
22021	1	1	56	784	194	195 2 217	291
194	3	30	564	194	195	211 263	299
22025	2	1	13	250	206	208 335	533
206	2	4	388	206	333	334 493	535
22029	2	3	215	81	212	217 40 247	327
215	1	170	30	215	244	246 282	385
22030	1	3	192	135	219	221 253	276
220	1	3	93	160	220	222 228 271	291
22038	1	5	213	780		238	256
235	1	2	217	1065	235	237 253	264
22040	1	1	255	22434	241	04 247 272 354 374	
238	3	250	31429	238	244	246 247 343 368 469	
22041	2	3	100	5009	240	16 263	312
239	3	166	4161	239	258	262 269	330
22043	1	1	135	3780	241	04 247 272	379
239	3	58	3654	239	244	246 288 335	468
22045	1	5	168	200	242	249	252
242	3	3	212	418	242	248 255	260

22049	1	1	372	462		246	249	08	256		278
	246	4	3	552	1016		246	254		288	293
22050	1	2	260	1327		247	249		282		335
	246	4	3	168	1335		247	277	279	315	349
22051	1	1	96	82		246	249	08	249		254
	246	4	3	169	90		246	255	249	258	262
22052	2	1	45	1888		389	250	08	330		489
	248	2	2	48	1545 388		248	258	329	466	491
22053	1	1	45	1760		249	250	08	286		424
	248	2	2	54	2134		248	250	263	414	430
22054	1	2	60	590		254	255	08	282		320
	254		3	41	551		254	269	355	320	408
22060	1	3	36	174		260	262	06	330		427
	262	3	3	58	184		262	262	329	368	430
22062	1	1	24	217		270	271	08	301		303
	270	5	2	31	294		270	300	301	305	317
22065	1	1	40	555		275			282		359
	275		2	40	582		275		277	349	369
22068	3	3	47	140		285	286	06	301	308	369
	285		2	42	160		285	296	301	302 360	385
22069	1	2	191	780		287	291	16	356		422
	285		3	202	750		287	339	355	411	430
22072	1	1	50	144		297	300	08	367		424
	299		2	44	213		299	360	365	411	457
22077	1	2	92	1715		325	325	16	356		468
	325	2	2	76	1793		325	329	355	452	492
22079	1	2	49	198		330	331	08	356		444
	331		3	44	142		331	336	355	390	457
22080	1	1	306	643		292	332	04	356		440
	331		3	217	285		331	336	355	390	455
22081	1	4	442	504		382	332	12	341		408
	331		3	239	514		331	336	338	388	430
22084	1	3	112	224		331	334	08	341		388
	331	4	2	97	206		331	336	338	385	534
22085	2	2	72	1799				401	04	429	528
	333		3	91	1705		406	402	427	471	534

22087	2	3	179	1571	337	339	12	356	483
338		3	204	1301	339	339	355	466	534
22091	1	1	100	92	345				483
345		3	85	92	345		353	281	491
22097	2	4	104	21	351	354	04		379
352		2	174	0	352	358	361		382
22098	2	3	825	4686	352	353	16	358	358
352		1	1106	4630	352	356	357	398	400
22099	1	4	27	16	353	353	08	364	374
353		2	18	10	353	355	361	381	382
22100	1	1	45	1899	356	358	08	367	468
356		2	40	1896	356	360	365	460	472
22101	2	1	32	923	358	359	04	392	452
358		2	64	877	358	360	389	440	456
22102	1	2	162	42	356	358	02	392	466
360		2	95	41	360	360	389	416	472
22103	2	2	47	447	362	363	08	370	515
362		2	42	516	362	365	369	484	518
22105	2	6	640	5179		366	06	376	519
364		2	617	3665	364	370	374	480	527
22131	1	3	49	56	386	399	04		422
391		2	61	0	391	400	404		426
23001	2	1	36	494	404	405	08	440	537
404		2	32	464	404	409	434	479	540
50620	1	1	80	894					140
045		3	234	1157	045		065		151
50641	2	3	158						240
075		1	79	380	075	084	108	144	326
50642	2	3	384						240
075		1	157	800	075	084	108	144	260
50643	2	3	179						240
075		1	195	981	075	084	108	144	249
50662	3	3	259	340	106	107	08		108
106		1	279	385	106	107	107	157	151
50692	3	3	151	2493					206
			192	2725	075	085	108	144	276

51003	2	1	92		179		181
179	2	116			179	179 267	251
51004	2	1	16		178		185
183	2	2			185	186	185
51007	2	3	131	48	212	217 36 247	332
215	1	93	379		215	222 223 292	382
51008	2	3	180	79	212	217 48 247	330
215	1	130	117		215	244 246 282	392
51014	2	1	90	4981		255 02 330	494
245	3	68	4217		245	258 329 368	497
51020	2	3	201	1048	369	374 08 429	447
373	2	99	408		373	374 427 447	455
52000	3	5	337	621 410	417	417 08 426	437
410	1	4	491	461 412	417	418 422 460	484
61014	2	41	271	017	018	020 04	147
016	3	30	358	018	018	024 030 108	149
61015	1	40	0		001		098
018	3	279	0		018	030 108	123
61018	2	92	125		024	026 08	077
024	3	28	85		024	027 028	082
61019	4	48	1825		042	047 16	076
045	3	68	735		045	048 051 066	145
61020	2	60	181		045	08 059	214
045	3	46	242		045	058 110	222
61023	3	53	396		082	084 08 098	192
082	3	69	488		082	089 096 073	194
61025	2	23	20	102	109	110 124	192
102	3	34	11	105	109	120 185	194
61026	5	342	468	111	123	126 24	135
111	3	130	125	112	123	133 134	171
62000	1	52	0		167	167 02	170
167	3	19	0		167	168	175
62001	4	132	739		193	194 213	266
193	5	73	890		193	196 197 264	302
62002	4	66	1002		191	195 16 236	384
195	3	86	807		195	218 228 384	403

62008	4	51	410	206	208	16	236	388
206		99	944	206	214	228	352	403
62011	5	433	552	251	252	16	273	276
251	1	330	492	251	269	272	341	349
62014	5	159	47	270	271	08	282	308
270	3	153	244	270	272	276	288	327
62015	2	102	386	326			335	431
281	2	97	447	281		333	417	435
62016	1	56	1093	288			316	432
311	3	21	25	311		311	426	436
62021	1	4	104	333	335	08	341	418
333	6	3	85	333	336	338	411	436
62025	1	24	251 368	365	366	08	376	405
365	2	38	224 370	365	371	374	388	407
62026	4	129	273	381			417 475	475
381	2	92	261	381		415	469 480	480
62027	2	94	0	389	391	08		391
	2	154	0	389	398	398		403
62028	2	56	710	392	393	08	416	445
392	3	2	38	392	398	415	431	479
62030	1	22	75 398	394	396	08	416	490
395	3	2	16	395	396	415	448	491
62031	3	126	218 399	394	397	16	408	409
395	1	4	231	395	399	412	431	435
62033	1	120	210	398	398	08	416	473
398	3	52	230	402	401	415	466	476
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72110	3	5	107 2095 037	036			057	232
006	2	110	1863 047	047		053	180	269
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72116	3	3	51 132	009				094
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72129	3	2	28	17	016			029		181
016	2	6	1		016		026	102		185
72138	3	2	56	36	023	032	033	08		160
023	2	43	280	029	032	036	041	133		161
72149	3	3	173	470	028	036	038	16	069	276
028	2	173	591	035	036	049	065	158		291
72150	3	3	108	256	029	034	035		045 420	465
029	7	2	70	626	033	034			180 438	494
72155	3	1	105	2370	033	033	16	040		170
033	1	2	91	1600	033	036	040	134		184
72157	3	2	35	356	035	034				167
035	4	40	258	037	038		044	120		170
72173	3	3	52	212	039	041	042		053 271	389
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039	2	2	33	15	040	041		051	110	233
72175	3	7	321	846	040	040	100	271	426 08 461 525	527
040	2	484	853	040	100	102	271	450	456 519 532	540
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72178	3	2	40	0	041	041	042			321
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72188				049						
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72191	3	1	40	81		048	048	08		060
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72194	3	3	58	250	050	048	056		069	222
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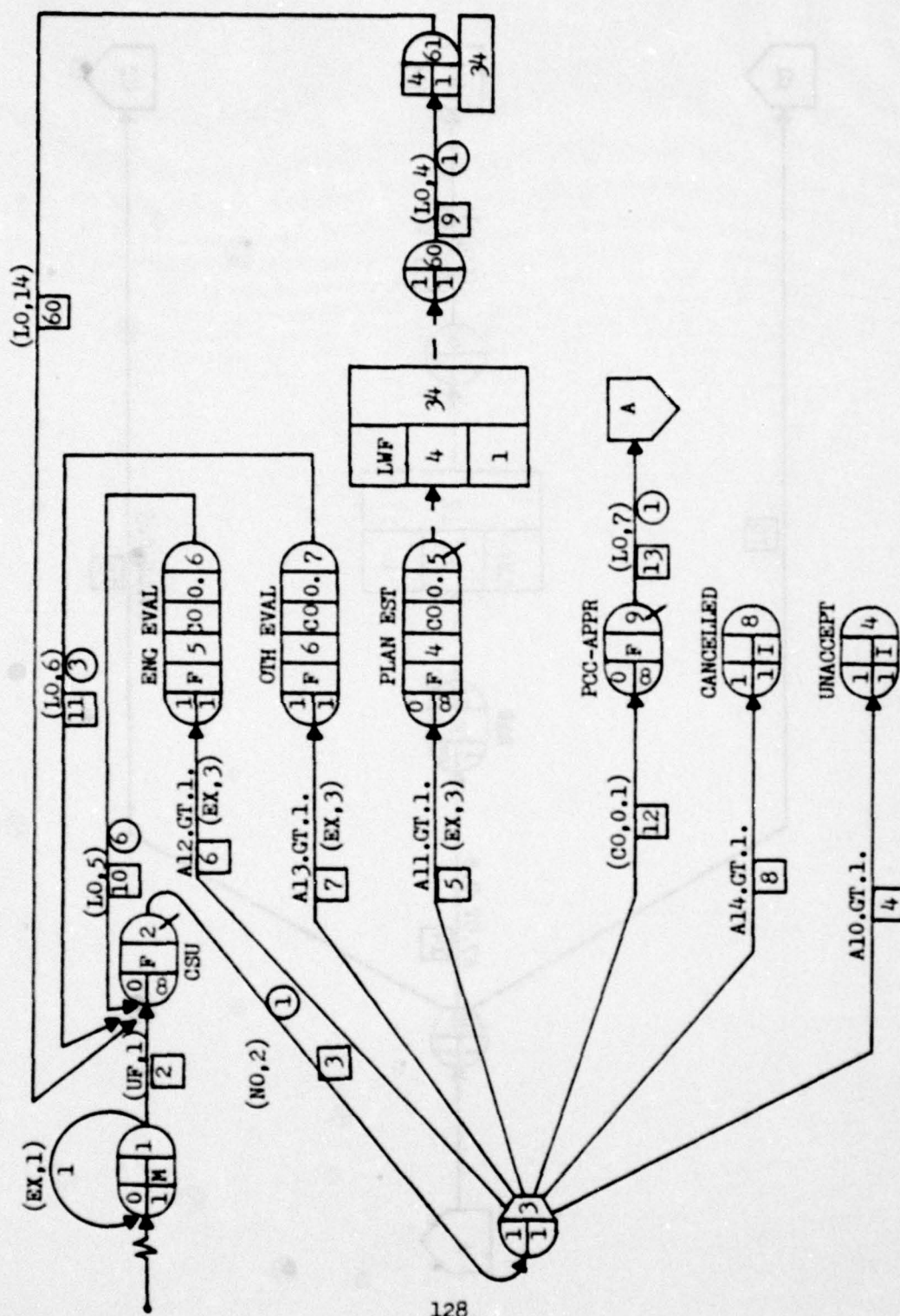
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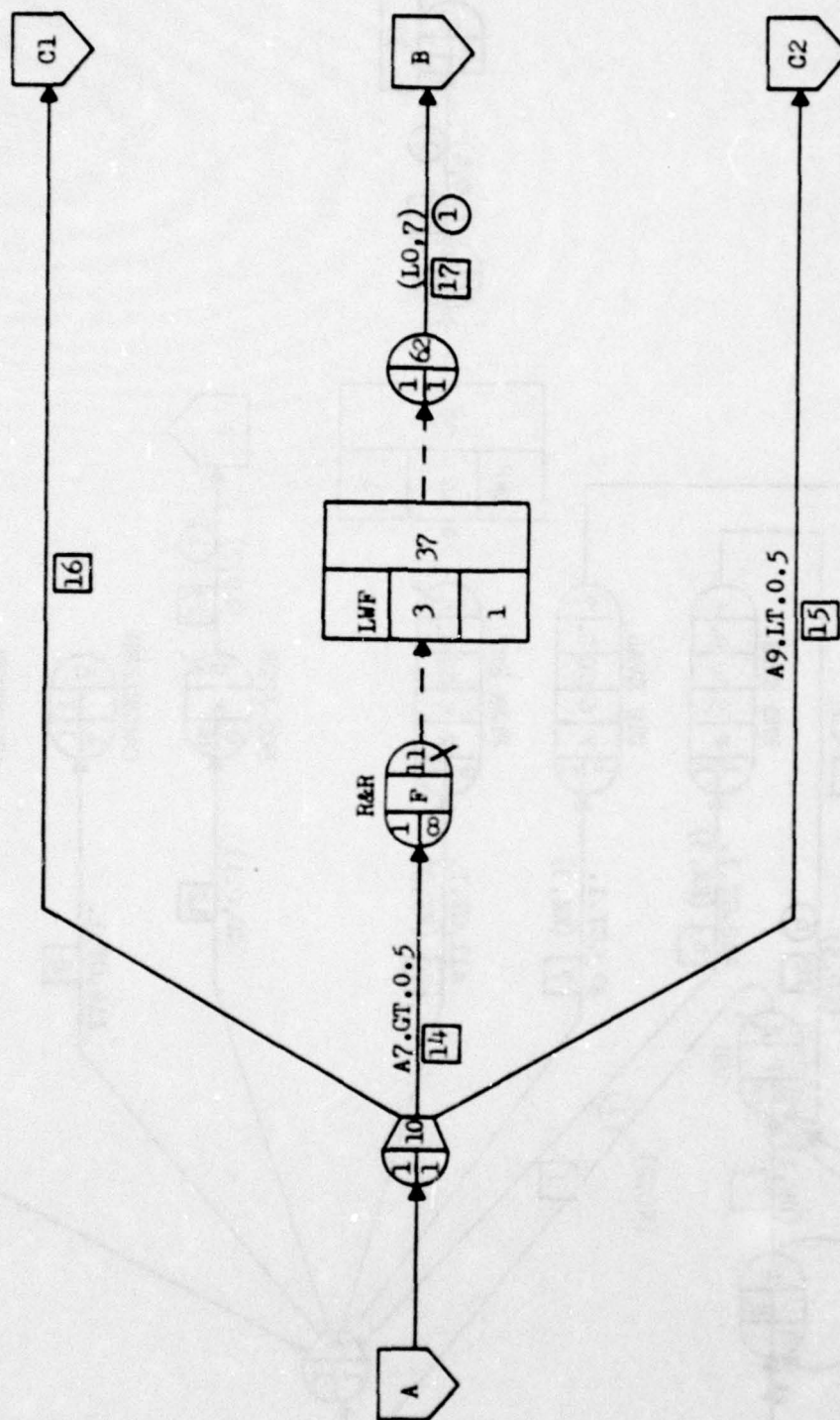
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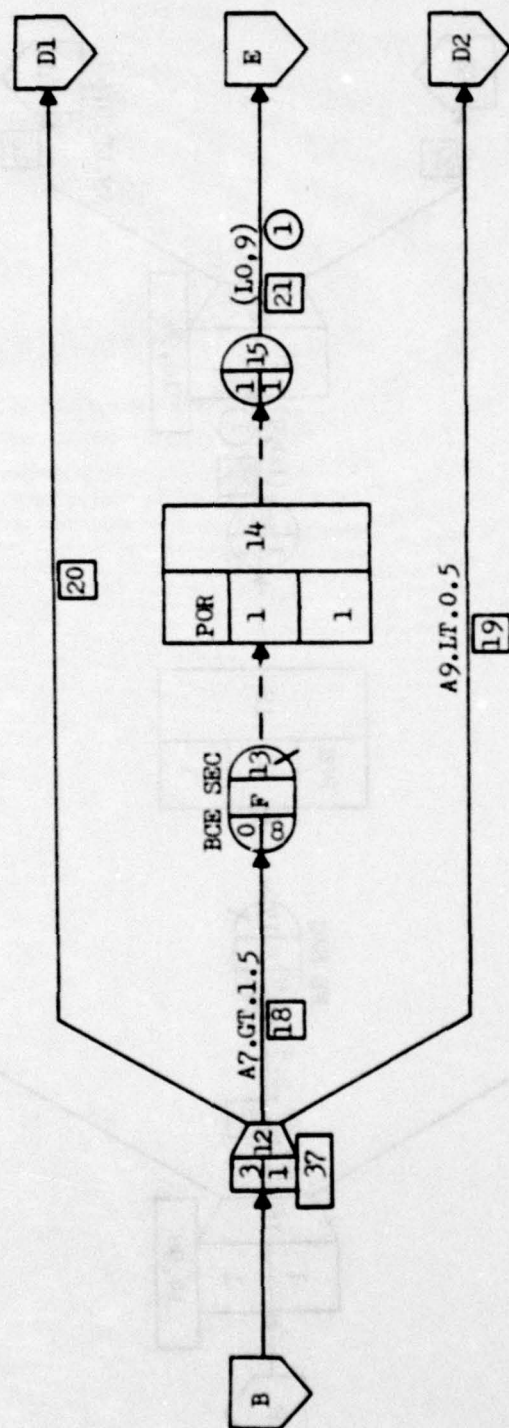
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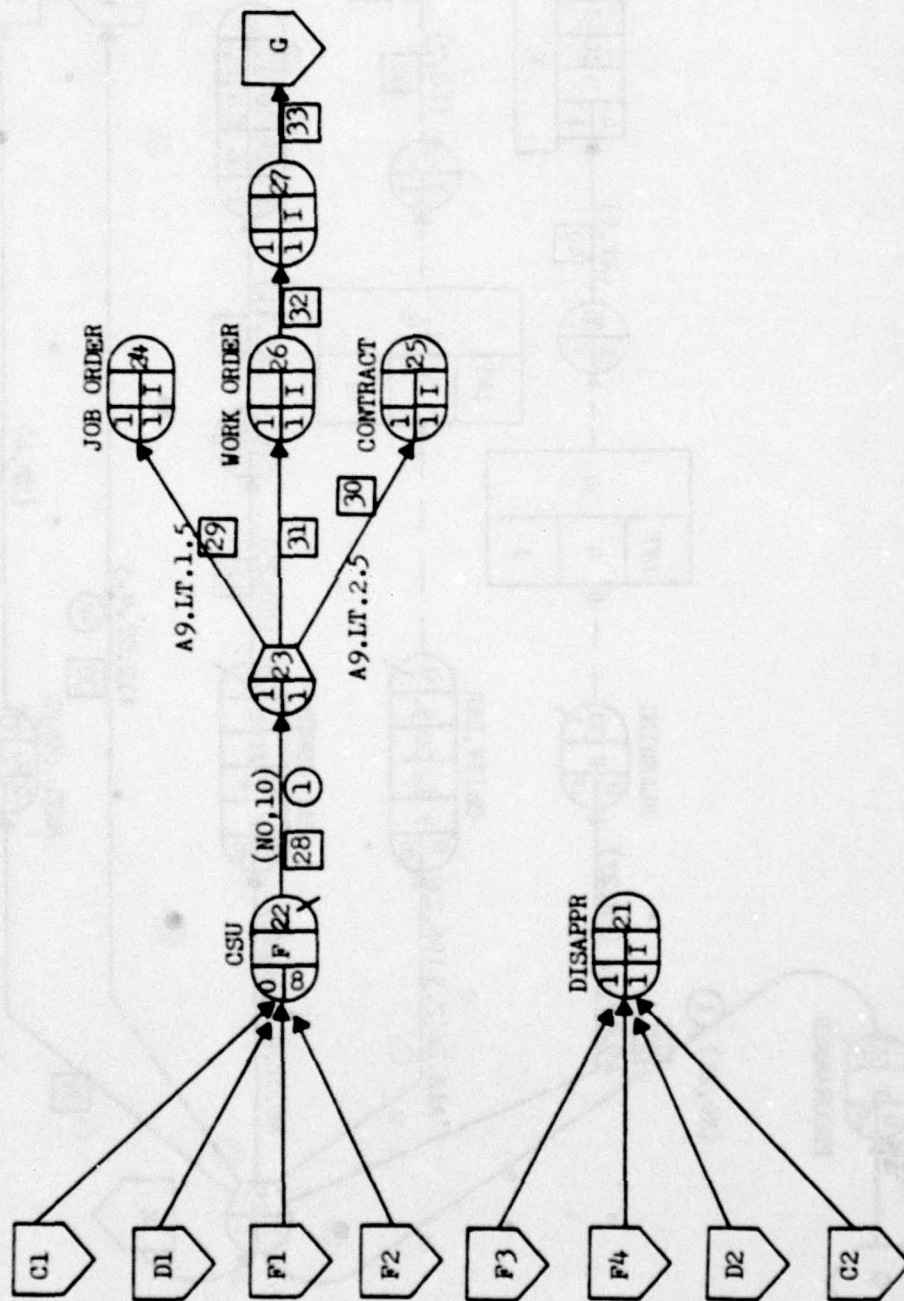
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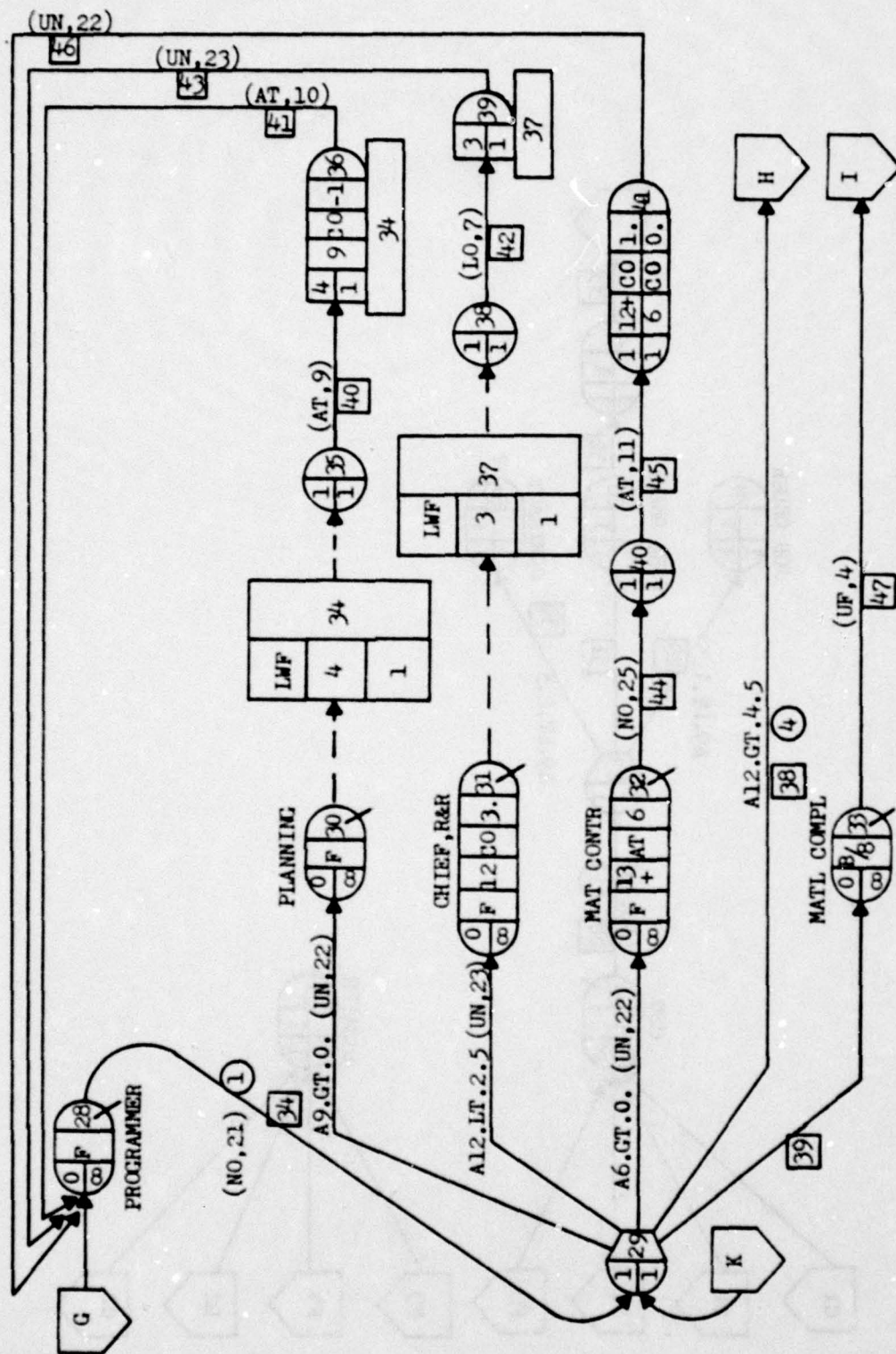
APPENDIX E
Q-GERT NETWORK MODEL

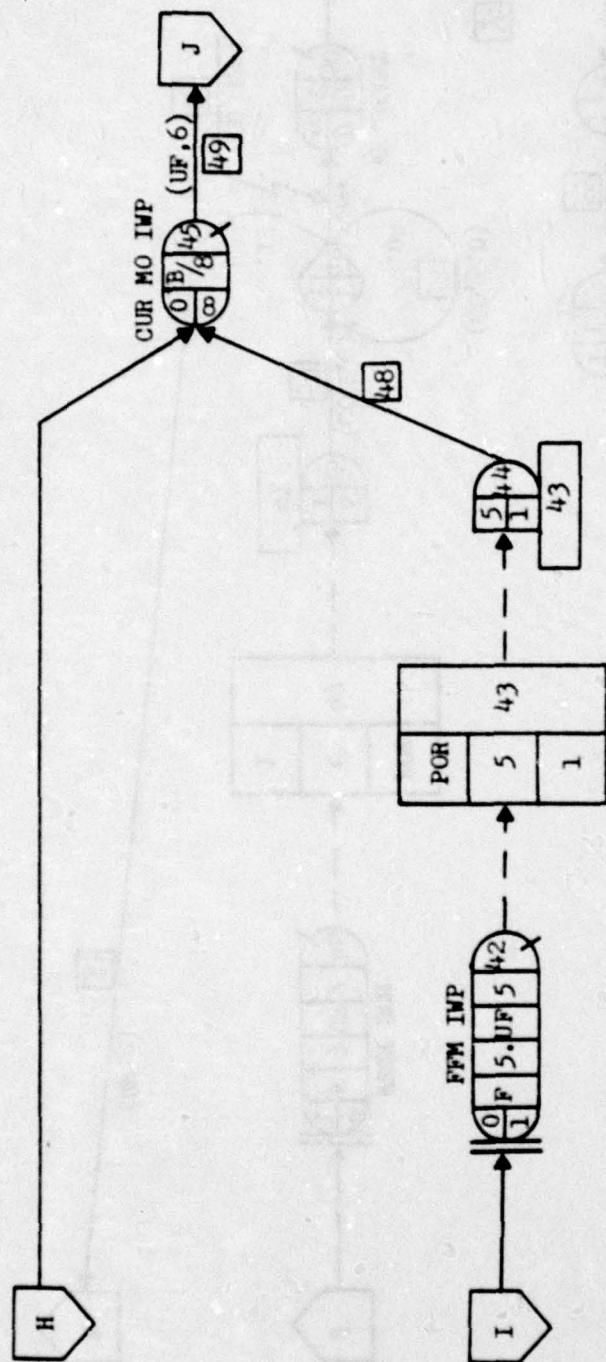




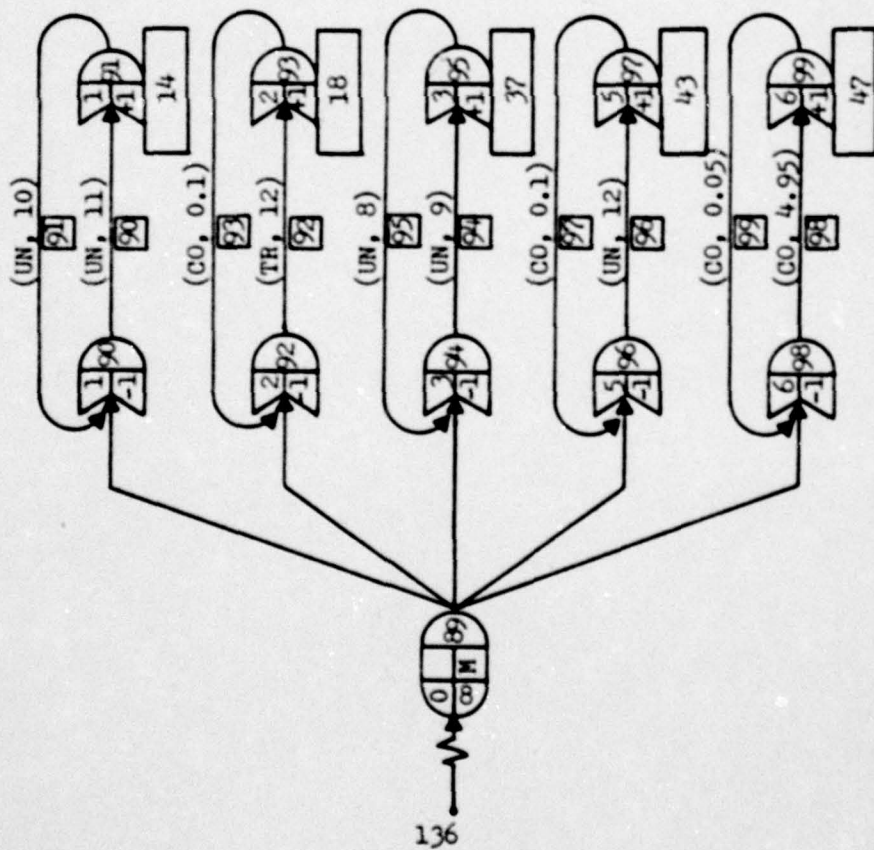












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 RES, 2/FB, 1, 18*
 RES, 3/R&R CH., 1, 37*
 RES, 4/Planners, 6, 34*
 RES, 5/Mo Prog, 1, 43*
 RES, 6/Wk Sched, 1, 47*

141

APPENDIX F
CODED Q-GERT MODEL

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 REG,10,1,1,F*
 QUE,11/R&R APPR,0,,D,F,(10)37*
 REG,62,1,1,D*
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 REG,15,1,1,D*
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 FRE,39,D,3,1,37*
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 REG,41,1,1,D*

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 QUE,45/CUMO IWP,0,,D,B/8*
 QUE,46/WEEK SCH,0,1,D,F,B,(10)47*
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 FRE,48,D,6,1,47*
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 ACT,6,2,LO,5,10/ENG EVAL,6*
 ACT,7,2,LO,6,11/OTH EVAL,3*
 ACT,3,9,CO,0.1,12,,6*
 ACT,9,10,LO,7,13/PCC APPR,1*
 ACT,10,11,,,14,,1,A7.GT.0.5*
 ACT,10,21,,,15,,2,A9.LT.0.5*
 ACT,10,22,,,16,,3*
 ACT,62,12,LO,7,17/R&R APPR,1*
 ACT,12,13,,,18,,1,A7.GT.1.5*
 ACT,12,21,,,19,,2,A9.LT.0.5*
 ACT,12,22,,,20,,3*
 ACT,15,16,LO,7,21/BCE,1*
 ACT,16,17,,,22,,1,A7.GT.2.5*
 ACT,16,21,,,23,,2,A9.LT.0.5*
 ACT,16,22,,,24,,3*
 ACT,19,20,LO,7,25/FB,1*
 ACT,20,21,,,26,,1,A9.LT.0.5*
 ACT,20,22,,,27,,2*
 ACT,22,23,NO,2,28/CSU CHAN,1*
 ACT,23,24,,,29,,1,A9.LT.1.5*
 ACT,23,25,,,30,,2,A9.LT.2.5*
 ACT,23,26,,,31,,3*
 ACT,26,27,,,32*
 ACT,27,28,UF,2,33*

ACT,28,29,NO,21,34/PGMR PRO,1*
 ACT,29,30,UN,22,35,,1,A9.GT.0.*
 ACT,29,31,UN,23,36,,2,A12.LT.2.5*
 ACT,29,32,UN,22,37,,3,A6.GT.0.0*
 ACT,29,45,,,38,,4,A12.GT.4.5*
 ACT,29,33,,,39,5*
 ACT,35,36,AT,9,40*
 ACT,36,28,AT,10,41*
 ACT,38,39,LO,7,42*
 ACT,39,28,UN,23,43*
 ACT,32,40,NO,25,44/M-C PROC,3*
 ACT,40,41,AT,11,45*
 ACT,41,28,UN,22,46*
 ACT,33,42,UF,4,47/PGM MO,1*
 ACT,44,45,,,48*
 ACT,45,46,UF,6,49/SCH WEEK,1*
 ACT,48,49,CO,2.0,50*
 ACT,49,49,CO,5.0,51,,0.04*
 ACT,49,28,UF,3,52,,0.12*
 ACT,49,50,CO,3.0,53,,0.84*
 ACT,50,51,UF,8,54/WK START,1*
 ACT,51,52,AT,14,55*
 SOU,89*
 ALT,90,D,1,-1*
 ALT,91,D,1,1,14*
 ALT,92,D,2,-1*
 ALT,93,D,2,1,18*
 ALT,94,D,3,-1*
 ALT,95,D,3,1,37*
 ALT,96,D,5,-1*
 ALT,97,D,5,1,43*
 ALT,98,D,6,-1*
 ALT,99,D,6,1,47*
 ACT,89,90,,,85*
 ACT,89,92,,,86*
 ACT,89,94,,,87*
 ACT,89,96,,,88*
 ACT,89,98,,,89*
 ACT,90,91,UN,11,90*
 ACT,91,90,UN,10,91*
 ACT,92,93,TR,12,92*
 ACT,93,92,CO,0.1,93*
 ACT,94,95,UN,9,94*
 ACT,95,94,UN,8,95*
 ACT,96,97,UN,12,96*

ACT,97,96,CO,0.1,97*	W.R. INTERARRIVAL TIME
ACT,98,99,CO,4.95,98*	CSU PROCESSING TIME
ACT,99,98,CO,0.05,99*	DELAY TO PLAN, DEE & OTHER
VAS,5,11,CO,0.0*	PLAN EST TIME
VAS,6,12,CO,0.0*	DEE EVAL TIME
VAS,7,13,CO,0.0*	OTHER EVAL TIME
VAS,36,9,CO,-1.0*	APPROVAL & AUTH TIME
VAS,31,12,CO,3.0*	R & R AVAILABLE
VAS,32,13+,AT,6*	R & R NON-AVAILABILITY
VAS,41,12+,CO,1.0,6,CO,0.0*	BCE AVAILABLE
VAS,42,14,UF,5*	BCE NON-AVAILABLE
VAS,46,14,UF,7*	FB NON-AVAIL & MO. PROG FREQ
RES,1/BCE,1,14*	OTHER PLAN EVAL DELAY
RES,2/FAC BD,1,18*	EST MH FLUC
RES,3/R&R CH,1,37*	EST MATL FLUC
RES,4/PLANNERS,6,34*	PRECEDENCE FLUC
RES,5/MO PROG,1,43*	PLANNING MH FLUC
RES,6/WK SCHED,1,47*	OTH PLAN DELAY FLUC
PAR,1,0.412,0.0,,0.2*	MATL LEADTIME FLUC
PAR,2,.05,0.,,0.01*	PGMR PROC
PAR,3,1.,0*	TIME TO PLN & TO & FM M.C.
PAR,4,0.482,0.0,,0.435*	TIME TO & FM CH R & R
PAR,5,33.417,0.0,,48.25*	M.C. PROC TIME
PAR,6,2.,0.0,,1.*	IN PROG TIME FLUC
PAR,7,0.01,0.0,,0.1*	EST MATL REORDER
PAR,8,,0.01,0.1*	
PAR,9,,0.0,0.5*	
PAR,10,,0.0,0.02*	
PAR,11,,0.5,1.5*	
PAR,12,,19.0,23.0*	
PAR,14,2.78,0.0,,5.884.*	
PAR,15,0.0,,127.55*	
PAR,16,0.0,,1894.53*	
PAR,17,0.0,,48.8*	
PAR,18,0.0,,0.8596*	
PAR,19,0.0,,14.333*	
PAR,20,0.0,,54.83*	
PAR,21,0.05,,0.01*	
PAR,22,,0.001,0.5*	
PAR,23,,0.001,0.2*	
PAR,25,0.02,0.0,,0.003*	
PAR,26,0.0,,31.565*	
PAR,27,100.,10.,1000.*	
FIN*	

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FUNCTION UF(IFN)
COMMON /QVAR/ NDE,NFTBU(100),NREL(100),NRELP(100),
&   NREL2(100),NRUN,NRUNS,NTC(100),PARAM(100,4),TBEG,TNOW
DIMENSION ATT(14), K(4)
C
C   GO TO (1,2,3,4,5,6,7,8),IFN
C
1  UF = 0.0
C
C   *   ASSIGNING VALUES TO ATTRIBUTES 1 TO 13
C
C   **   ATTRIBUTE 1 - WORK CLASS - 0-BLANK 1-MAINT 2-REPAIR
C           3-CONSTRUCTION
C
C   **   ATTRIBUTE 2 - SPECIAL INTEREST CODE - 1-CMD INT
C           2-FIRE PROT 3-HOSP 4-8TH AF 5-COMMUN 6-W.S.A.
C           7-DORM REHAB 8-BOMBCOMP
C
C   **   ATTRIBUTE 3 - PRIORITY
C
C   **   ATTRIBUTE 4 - NUMBER OF SHOPS
C
C   **   ATTRIBUTE 5 - ESTIMATED MANHOURS
C
C   **   ATTRIBUTE 6 - ESTIMATED MATERIALS
C
C   **   ATTRIBUTE 7 - APPROVAL AUTHORITY - 0-PCC 1-R&R 2-BCE
C           3-FB OR HIGHER
C
C   **   ATTRIBUTE 8 - PRECEDENCE
C
C   **   ATTRIBUTE 9 - DISPOSITION - 0-DISAPPROVED 1-JOB ORD
C           2-CONTRACT 3-WORK ORDER
C
C   **   ATTRIBUTES 10 THRU 14 - WORK REQUEST ROUTING
C           10 - UNACCEPTIBLE
C           11 - NEEDS PLANNING EVALUATION
C           12 - NEEDS ENGINEERING EVALUATION
C           13 - NEEDS OTHER EVALUATION
C           14 - SENT BACK OR CANCELLED AFTER EVALUATIONS
C
R1 = DRAND(-1.)
R2 = DRAND(-2.)
R3 = DRAND(-3.)
R4 = DRAND(-4.)
K(1) = 0
K(2) = 0
K(3) = 1
K(4) = 1

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IF (R2.LT.0.638) GO TO 10
IF (R2.LT.0.801) GO TO 14
IF (R2.LT.0.863) GO TO 18
IF (R2.LT.0.910) GO TO 21
IF (R2.LT.0.926) GO TO 24
IF (R2.LT.0.953) GO TO 25
IF (R2.LT.0.984) GO TO 27
IF (R2.LT.0.992) GO TO 29
K(1) = 3
K(2) = 8
IF (R4.GT.0.5) K(4) = 2
GO TO 30
10 IF (R1.GT.0.516) GO TO 13
IF (R1.GT.0.342) GO TO 12
IF (R1.GT.0.110) GO TO 11
K(3) = 2
IF (R3.GT.0.294) K(3) = 3
IF (R3.GT.0.941) K(3) = 4
IF (R4.GT.0.278) K(4) = 2
IF (R4.GT.0.611) K(4) = 3
IF (R4.GT.0.667) K(4) = 4
IF (R4.GT.0.944) K(4) = 5
GO TO 30
11 K(1) = 1
K(3) = 2
IF (R3.GT.0.222) K(3) = 3
IF (R3.GT.0.944) K(3) = 4
IF (R4.GT.0.243) K(4) = 2
IF (R4.GT.0.675) K(4) = 3
IF (R4.GT.0.756) K(4) = 4
IF (R4.GT.0.864) K(4) = 5
IF (R4.GT.0.891) K(4) = 6
IF (R4.GT.0.945) K(4) = 7
GO TO 30
12 K(1) = 2
IF (R3.GT.0.148) K(3) = 2
IF (R3.GT.0.629) K(3) = 3
IF (R4.GT.0.259) K(4) = 2
IF (R4.GT.0.592) K(4) = 3
IF (R4.GT.0.888) K(4) = 4
IF (R4.GT.0.925) K(4) = 5
IF (R4.GT.0.962) K(4) = 6
GO TO 30
13 K(1) = 3
IF (R3.GT.0.040) K(3) = 2
IF (R3.GT.0.707) K(3) = 3
IF (R3.GT.0.880) K(3) = 4
IF (R4.GT.0.317) K(4) = 2
IF (R4.GT.0.512) K(4) = 3

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IF (R4.GT.0.756) K(4) = 4
IF (R4.GT.0.878) K(4) = 5
IF (R4.GT.0.927) K(4) = 6
IF (R4.GT.0.964) K(4) = 7
GO TO 30
14 K(2) = 1
IF (R1.GT.0.486) GO TO 17
IF (R1.GT.0.257) GO TO 16
IF (R1.GT.0.057) GO TO 15
K(3) = 4
K(4) = 3
IF (R4.GT.0.667) K(4) = 5
GO TO 30
15 K(1) = 1
K(3) = 2
IF (R3.GT.0.143) K(3) = 3
IF (R3.GT.0.572) K(3) = 4
K(4) = 2
IF (R4.GT.0.143) K(4) = 3
IF (R4.GT.0.429) K(4) = 4
IF (R4.GT.0.858) K(4) = 5
GO TO 30
16 K(1) = 2
K(3) = 2
IF (R3.GT.0.125) K(3) = 3
IF (R3.GT.0.625) K(3) = 4
K(4) = 2
IF (R4.GT.0.111) K(4) = 3
IF (R4.GT.0.555) K(4) = 4
IF (R4.GT.0.888) K(4) = 6
GO TO 30
17 K(1) = 3
K(3) = 2
IF (R3.GT.0.389) K(3) = 3
IF (R3.GT.0.611) K(3) = 4
IF (R4.GT.0.304) K(4) = 2
IF (R4.GT.0.434) K(4) = 3
IF (R4.GT.0.651) K(4) = 4
IF (R4.GT.0.694) K(4) = 5
IF (R4.GT.0.911) K(4) = 6
GO TO 30
18 K(2) = 2
IF (R1.GT.0.375) GO TO 20
IF (R1.GT.0.250) GO TO 19
K(1) = 1
K(3) = 2
IF (R3.GT.0.750) K(3) = 3
IF (R4.GT.0.500) K(4) = 2
GO TO 30

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19 K(1) = 2
   K(3) = 2
   GO TO 30
20 K(1) = 3
   K(3) = 3
   IF (R4.GT.0.50) K(4) = 2
   IF (R4.GT.0.70) K(4) = 3
   IF (R4.GT.0.90) K(4) = 4
   GO TO 30
21 K(2) = 3
   IF (R1.GT.0.8) GO TO 23
   IF (R1.GT.0.4) GO TO 22
   K(3) = 2
   IF (R3.GT.0.750) K(3) = 3
   IF (R4.GT.0.333) K(4) = 2
   IF (R4.GT.0.667) K(4) = 4
   IF (R4.GT.0.833) K(4) = 5
   GO TO 30
22 K(1) = 1
   K(3) = 3
   IF (R4.GT.0.50) K(4) = 3
   IF (R4.GT.0.75) K(4) = 5
   GO TO 30
23 K(1) = 3
   K(3) = 2
   IF (R3.GT.0.5) K(3) = 4
   K(4) = 2
   IF (R4.GT.0.5) K(4) = 3
   GO TO 30
24 K(1) = 1
   K(2) = 4
   K(3) = 2
   IF (R3.GT.0.25) K(3) = 3
   IF (R4.GT.0.50) K(4) = 2
   IF (R4.GT.0.75) K(4) = 3
   GO TO 30
25 K(2) = 5
   IF (R1.GT.0.25) GO TO 26
   K(1) = 1
   K(3) = 2
   GO TO 30
26 K(1) = 3
   K(3) = 2
   IF (R3.GT.0.667) K(3) = 3
   IF (R4.GT.0.2) K(4) = 2
   IF (R4.GT.0.4) K(4) = 3
   IF (R4.GT.0.6) K(4) = 6
   IF (R4.GT.0.8) K(4) = 7
   GO TO 30

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27 K(2) = 6
   IF (R1.GT.0.167) GO TO 28
   K(1) = 1
   K(3) = 3
   K(4) = 4
   GO TO 30
28 K(1) = 3
   K(3) = 2
   K(4) = 2
   IF (R4.GT.0.143) K(4) = 3
   IF (R4.GT.0.714) K(4) = 4
   IF (R4.GT.0.857) K(4) = 6
   GO TO 30
29 K(1) = 3
   K(2) = 7
   K(3) = 2
   IF (R3.GT.0.5) K(3) = 3
   IF (R4.GT.0.5) K(4) = 3
30 DO 31 I=1,4
   ATT(I) = FLOAT(K(I))
31 CONTINUE
   WC = 0.0
   SI = 0.0
   IF (K(1).EQ.1) WC = 40.8196
   IF (K(1).EQ.2) WC = 97.2647
   IF (K(2).EQ.1) SI = 89.4413
   IF (K(2).EQ.4) SI = 111.4747
   IF (K(2).EQ.5) SI = 68.7316
   IF (K(2).EQ.6) SI = 91.9906
   IF (K(2).EQ.8) SI = 141.4610
32 ATT(5) = ATT(4)*36.8495 + WC + SI - 6.3595 + NO(15)
   IF (ATT(5).LE.8.0) GO TO 32
   WC = 0.0
   SI = 0.0
   IF (K(1).EQ.1) WC = 863.3730
   IF (K(1).EQ.2) WC = 434.8407
   IF (K(2).EQ.1) SI = -344.6478
   IF (K(2).EQ.4) SI = -1773.1925
   ATT(6) = ATT(5)*6.0976 - ATT(4)*185.8713 +
&      WC + SI + 475.9245 + NO(16)
   IF (ATT(6).LT.0.0) ATT(6) = 0.0
   ATT(7) = 0.0
   ESTCT = ATT(5)*12.67 + ATT(6)
   IF (K(1).EQ.3) GO TO 35
   IF (K(1).EQ.2) GO TO 34
   IF (K(1).EQ.1) GO TO 33
   IF (ESTCT.GE.10000.) ATT(7) = 1.0
   IF (ESTCT.GE.50000.) ATT(7) = 2.0
   GO TO 36

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33 IF (ESTCT.GE.250000.) ATT(7) = 2.0
   IF (ESTCT.GE.100000.) ATT(7) = 3.0
   GO TO 36
34 IF (ESTCT.GE.25000.) ATT(7) = 2.0
   IF (ESTCT.GE.50000.) ATT(7) = 3.0
   GO TO 36
35 IF (ESTCT.GE.2500.) ATT(7) = 1.0
   IF (ESTCT.GE.10000.) ATT(7) = 2.0
   IF (ESTCT.GE.25000.) ATT(7) = 3.0
36 WC = 0.0
   SI = 0.0
   PR = 0.0
   IF (K(1).EQ.1) WC = 15.0425
   IF (K(1).EQ.2) WC = 21.4988
   IF (K(1).EQ.3) WC = 24.0900
   IF (K(2).EQ.1) SI = -16.3056
   IF (K(2).EQ.5) SI = 70.9451
   IF (K(3).EQ.3) PR = 22.0761
   ATT(8) = 1000.0/(ATT(5)*0.05852 - ATT(6)*0.001928 +
&      WC + SI + PR + 9.2613 + NO(17))
   R = DRAND(-5.)
   ATT(9) = 0.0
   IF (R.GE.0.101) ATT(9) = 1.0
   IF (R.GE.0.487) ATT(9) = 2.0
   IF (R.GE.0.582) ATT(9) = 3.0
   DO 37 I=10,14
   ATT(I) = 0.0
37 CONTINUE
   R = DRAND(-6.)
   IF (R.LE.0.198) ATT(10) = 2.0
   R = DRAND(-7.)
   IF (K(1).EQ.3) GO TO 38
   IF (R.LE.0.21) ATT(11) = 2.0
   GO TO 39
38 IF (R.LE.0.890) ATT(11) = 2.0
39 R = DRAND(-8.)
   IF (R.LE.0.0614) ATT(12) = 2.0
   R = DRAND(-9.)
   IF (R.LE.0.01172) ATT(13) = 2.0
   R = DRAND(-10.)
   IF (R.LE.0.08265) ATT(14) = 2.0
   CALL PUTAT(ATT)
   RETURN

C
C *   ASSIGNING VALUES TO ATTRIBUTES 9 THRU 13
C
C **  ATTRIBUTE 9 - PLANNING MANDAYS
C
C **  ATTRIBUTE 10 - OTHER PLANNING DELAY

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C
C  ** ATTRIBUTE 11 - MATERIAL LEADTIME
C
C  ** ATTRIBUTE 12 - WORK ORDER ROUTING INDICATOR
C
C  ** ATTRIBUTE 13 - ACTUAL MATERIALS-INITIALIZED TO ZERO
C
2 CALL GETAT(ATT)
DO 40 I=9,14
ATT(I) = 0.0
40 CONTINUE
DO 41 I=1,4
K(I) = IFIX(ATT(I) + 0.2)
41 CONTINUE
WC = 0.0
SI = 0.0
PR = 0.0
IF (K(1).EQ.1) WC = -0.3366
IF (K(2).EQ.6) SI = 0.7448
IF (K(2).EQ.8) SI = -1.7235
IF (K(3).EQ.1) PR = 1.5596
IF (K(3).EQ.2) PR = -0.2977
IF (K(3).EQ.3) PR = -0.4443
IF (K(3).EQ.4) PR = -0.5476
ATT(9) = ATT(4)*0.06634 + ATT(5)*0.000775 + WC + SI +
6 PR + 0.9173 + NO(18)
IF (ATT(9).LT.0.0) ATT(9) = 0.0
WC = 0.0
SI = 0.0
PR = 0.0
IF (K(1).EQ.3) WC = -2.9921
IF (K(2).EQ.1) SI = 3.3375
IF (K(2).EQ.7) SI = 69.691
IF (K(3).EQ.2) PR = 4.4593
ATT(10) = ATT(9)*2.6297 + WC + SI + PR + 3.0417 + NO(19)
42 IF (K(1).EQ.1) WC = -10.2961
IF (K(1).EQ.2) WC = 38.6771
IF (K(1).EQ.3) WC = 20.8784
IF (K(2).EQ.1) SI = -36.7407
IF (K(2).EQ.2) SI = 19.4910
IF (K(2).EQ.3) SI = -21.5572
IF (K(2).EQ.5) SI = -50.4506
IF (K(3).EQ.1) PR = -87.2948
IF (K(3).EQ.2) PR = -38.8464
IF (K(3).EQ.3) PR = -27.9634
IF (K(3).EQ.4) PR = -44.1655
59 ATT(11) = ATT(4)*2.8997 + ATT(6)*0.0041 +
6 WC + SI + PR + 87.1651 + NO(20)
IF (ATT(11).LT.1.0) ATT(11) = 1.0

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        IF (IFN.EQ.3) GO TO 61
        CALL PATRB(ATT(9),9)
        CALL PATRB(ATT(10),10)
        CALL PATRB(ATT(11),11)
        CALL PATRB(ATT(12),12)
        CALL PATRB(ATT(13),13)
        CALL PATRB(ATT(14),14)
        RETURN
C
C      *   ASSIGNING NEW VALUES TO ATTRIBUTES 6 AND 11
C
C      **   ATTRIBUTE 6 - ESTIMATED MATERIALS
C
C      **   ATTRIBUTE 11 - MATERIAL LEADTIME
C
3  UF = 0.0
    CALL GETAT(ATT)
    ATT(6) = TR(27)
    DO 60 I = 1,4
      K(I) = IFIX(ATT(I) + 0.2)
60  CONTINUE
    GO TO 42
61  ATT(12) = 5.0
    CALL PATRB(ATT(6),6)
    CALL PATRB(ATT(11),11)
    CALL PATRB(ATT(12),12)
    RETURN
C
C      *   DETERMINING WHETHER THE FIRST FUTURE MONTH
C      IWP IS FULL YET.
C
4  UF = 0.1
    CALL PATRB(0.0,14)
    AHR = GATRB(5) + AHR
    RHR = 20000. - AHR
    IF (RHR.LE.0.0) RETURN
    NREL2(42) = NREL2(42) + 1
    CALL PATRB(2.0,14)
    RETURN
C
C      *   UNFILLING THE FIRST FUTURE MONTH IWP.
C
5  AHR = AHR - GATRB(5)
    IF (GATRB(14).LT.1.) GO TO 62
    NREL2(42) = NREL2(42) - 1
62  UF = 0.0
    RETURN
C

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C  * DETERMINING WHETHER NEXT WEEKS SCHEDULE
C  IS FULL YET.
C
6  UF = 0.1
   BHR = GATRB(5) + BHR
   RHR = 5000. - BHR
   IF (RHR.LE.0.0) RETURN
   NREL2(46) = NREL2(46) + 1
   CALL PATRB(2.0,14)
   RETURN
C
C  * UNFILLING NEXT WEEKS SCHEDULE TO THE SHOPS.
C
7  BHR = BHR - GATRB(5)
   IF (GATRB(14).LT.1.) GO TO 63
   NREL2(46) = NREL2(46) - 1
63 UF = 0.0
   RETURN
C
C  * DETERMINING THE ACTUAL TIME THE JOB WILL BE IN
C  THE SHOPS (ATTRIBUTE 14) AND THE SERVICE TIME --
C  TIME BEFORE THE NEXT JOB CAN START.
C
8  CALL GETAT(ATT)
   DO 64 I=1,3
   K(I) = IFIX(ATT(I)+0.2)
64 CONTINUE
   WC = 0.0
   SI = 0.0
   PR = 0.0
   IF (K(1).EQ.1) WC = 7.771
   IF (K(2).EQ.1) SI = 15.209
   IF (K(3).EQ.1) PR = -19.503
   IF (K(3).EQ.2) PR = -25.540
   IF (K(3).EQ.3) PR = -25.663
   IF (K(3).EQ.4) PR = -33.486
   R = ATT(4)*(-1.98) + ATT(5)*0.0912 +
6   WC + SI + WC + PR + 34.963 + NO(26)
   IF (R.LT.0.5) R = 0.5
   CALL PATRB(R,14)
   IF (ATT(4).LE.0.5) ATT(4) = 1.0
   UF = (ATT(5)/16.0)/ATT(4)
   IF (UF.LT.0.01) UF = 0.01
   RETURN
END

```

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BIOGRAPHICAL SKETCHES

Captain Arnold was awarded his Bachelor's degree at North Carolina State University, Raleigh, where he was commissioned in the Air Force through the AFROTC program. His career has included positions as Base Architect and Project Engineer; and he was serving as Base Comprehensive Planner with the 3700th Civil Engineering Squadron, Lackland AFB (ATC), Texas, when he was selected to attend AFIT. Upon graduation, he was assigned to 51st Civil Engineering Squadron (PACAF), Osan Air Base, Korea, as Chief of Resources and Requirements.

Captain Fogleman was awarded his Bachelor of Science in Engineering Operations from North Carolina State University in 1971. He also earned a Bachelor of Science in Textiles Technology in 1972, and was commissioned through the AFROTC program. He was stationed at Barksdale AFB (SAC), Louisiana, serving as the Civil Engineering Funds Manager; and at Eielson AFB (AAC), Alaska, as the Chief, Programs Development Section, Base Civil Engineering. Upon graduation, he was assigned to the Directorate of Maintenance, Deputy for Engineering and Services, Air Force Systems Command, Andrews AFB, Maryland.